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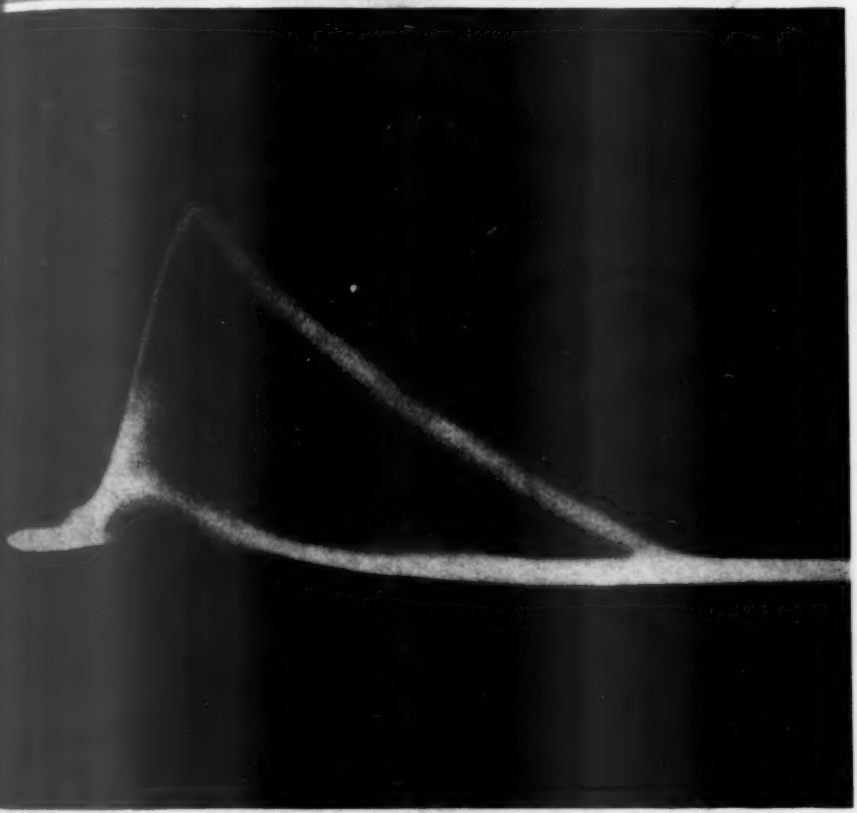
TECHNIQUES AND APPLICATIONS OF NUCLEAR SCIENCE AND ENGINEERING

August, 1950



Gamma-ray pulse from Au-198; see p. 89

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Techniques and Applications of Nuclear Science and Engineering

Alpha Radioactivity and the Stability of Heavy Nuclei... 3
I. PERLMAN

Distributed Beta Sources in Uniformly Absorbing Media—II...19
HARALD H. ROSSI and R. HOBART ELLIS, Jr.

Biological Syntheses of Radioisotope-Labeled Compounds...26
NATHAN H. WOODRUFF and E. EUGENE FOWLER

Practical Aspects of Surface Decontamination...42
P. C. TOMPKINS, O. M. BIZZELL, and C. D. WATSON

Cavity Ionization Chamber for Measurement of Absorbed X-Radiation Energy...55
THEODORE J. WANG

What Are the Prospects for Industrial Nuclear Power?...72
EUGENE AYRES, CHARLES A. THOMAS

BOOKS.....79 CROSS SECTIONS.....82
NUCLEONIC EVENTS.....88 PRODUCTS AND MATERIALS.....94

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GENERAL ELECTRIC

ALPHA RADIOACTIVITY and the Stability of Heavy Nuclei

This account reflects the important advances made in the last few years toward completing the picture of stability of heavy nuclei and predicting structures of unknown species. To the great fund of information on nuclear properties, to which these advances have led us, were recently added data on the new elements, berkelium (Bk) and californium (Cf)

By I. PERLMAN

Department of Chemistry and Radiation Laboratory
University of California, Berkeley, California

NONE OF THE THEORIES for the creation of elements limits their number to those that are our earthly heritage. However, there is a compelling thermodynamic reason why heavy elements tend to degrade into lighter ones, and the first obvious manifestation of this protest against indefinite increase in atomic (or more properly nuclear) size is alpha radioactivity.

Therefore, in the first instance, we may be sure that primordial matter contained, in unknown number, transuranium elements which decayed through geological time, and from the properties of those which have been prepared artificially, we know that they must essentially have disappeared fairly early in the history of the earth.

Beyond these elements, perhaps others were limited in addition by other forms of instability such as spontaneous fission or the inability of "orbital" electrons to exist outside of the nucleus.

Conditions for Alpha Instability

To visualize better the significance of alpha radioactivity, we may first conceive of the construction of heavy nuclei by the successive addition of neutrons and protons to a simple nucleus. It does not matter in what order we add the neutrons and protons since, within the nucleus, the one will convert to the other to establish a particular ratio characteristic of stable nuclei in that region.

These neutron-proton interconversions are the cause and essence of beta radioactivity. With a few minor exceptions, the criterion for stability and existence in nature of a nucleus outside of the heavy-element region is its beta stability.

Considering now only the beta stable nuclei, there is a progressive decrease in the average energy which binds the nucleons together as the number of protons increases, because of the coulombic repulsion of the proton charges. The driving force toward losing positive charged nucleons finally results in the general appearance of alpha radioactivity.

Two questions immediately arise. Why does the nucleus shed alpha particles (helium nuclei) rather than simpler or more complex units containing positive charge? Why does it not rid itself of the alpha particles instan-

taneously instead of, as in the case of uranium, waiting one billion years on the average?

The first question has two answers, the first of which applies to simpler bodies such as the proton itself. It turns out that it is more economical to emit protons in combination as alpha particles than singly because of the great stability (high binding energy) of the alpha particle. In fact, the proton in the alpha particle weighs about 7 Mev less than it does by itself, and no heavy nuclei are known that are thermodynamically unstable toward free proton emission.

The reason alpha particles are not emitted instantaneously is that the nucleus is surrounded by a potential energy barrier considerably higher than the energy at which the alpha particle rests and, in order to leave the nucleus, it must "leak through" the barrier by a mechanism explained by quantum mechanics. The rate of barrier penetration is extremely sensitive to the barrier size and to the energy of the alpha particle. The latter factor is principally responsible for the prodigious variation in alpha-decay half-lives that are known.

The reason fragments larger than alpha particles are not emitted is based on similar consideration of kinetics and may best be explained by an example. Thorium of mass number 230 (ionium) reaches Pb^{210} (radium D) by emission of four successive alpha particles whose total decay energy is about 21 Mev. If we were now to cause these four helium atoms to coalesce into an atom of O^{16}, an additional 15 Mev would be realized. This would mean that the decay energy of Th^{230} by oxygen emission would be 36 Mev. Despite this large potential toward oxygen emission, the increased barrier toward a particle with eight units of charge is sufficient to make the half-life toward this mode of decay some 10^{20} times as long as for emission of the 4.7-Mev alpha particle of Th^{230}. Obviously, there is no hope of observing such slow modes of decay.

In summary, we may say that somewhere near the middle of the periodic system, the driving force toward alpha-particle emission crosses some critical value, making this mode of decay thermodynamically possible for the average nucleus. It does not, however, reach a level where the rate is observable until the region above lead. We shall see that perturbations of the general trend in nuclear stability cause the half-lives to vary remarkably in the heavy element region and even bring about the appearance of an island of alpha radioactivity in the rare-earth region.

Alpha-Decay Measurements

Studies associated with the alpha-decay process have yielded such wealth of important information of nuclear properties that a brief summary may be in order.

Perhaps the most famous of these studies resulted in the enunciation by Rutherford of the nuclear atom. In observing the scattering of alpha particles when they strike heavy atoms, he deduced that the large-angle scattering could be explained only if the mass and positive charge of the atom were centered in a body of dimensions some 10,000 times smaller than those of the atom itself. This conclusion arises from the need of a strong electric field (centered in a heavy mass) to deflect a particle with the charge and momentum of the alpha particle. This can come about only if the atom's positive charge and, likewise, its mass are centered in an extremely small volume.

One of the implications of these scattering experiments as they defined nuclear dimensions was the necessity of assuming a potential barrier surrounding the nucleus several times higher than the energies of the alpha particles. While this explained why

alpha particles directed at a heavy atomic nucleus may not enter, it left one with an unanswered question as to how the alpha particles circumvent this wall in leaving the nucleus in the first place. The answer came simultaneously in 1928 from Gurney and Condon (*1*) and from Gamow (*2*) who used the then new quantum mechanics to explain how the wave nature of a particle allows it a finite probability of penetrating a region forbidden to it by classical theory.

The alpha particle within the nucleus encounters the barrier about 10^{20} times each second and eventually finds its way through, while a particle outside has only a very small chance of getting through the barrier in its single fleeting contact as it flies by. Parenthetically, it may be pointed out that one of the important functions of a particle accelerator is to bring charged particles to energies that allow them to go over the potential barrier and thus reach within the nucleus at will.

The theory for alpha decay was remarkably successful in general. Recently there have been some further advances which shed light on the nature of the process and have to do with the nuclear type as it affects prohibition of alpha decay.

Of far-reaching, practical importance in a number of studies is the fact that an alpha emitter gives off monoenergetic particles whose energies may be measured with a high degree of precision. This makes it possible not only to *detect* but also to *identify* fantastically small numbers of atoms through their characteristic alpha particles. Under favorable conditions, it is possible to identify completely a radioactive species having available a total of only a few hundred atoms. Coupled with the extreme sensitivity of measuring an alpha emitter is the newly acquired facility of predicting accurately alpha-decay properties of unknown species. These empirical correlations have a number of important functions.

The discovery of new transuranium elements is an excellent case in point concerning the power of identification of alpha emitters.

In the recent announcement of the discovery of an isotope of californium (element 98, symbol, Cf), Thompson, Street, Ghiorso, and Seaborg (*3*) reported the irradiation of microgram quantities of curium (element 96) with cyclotron-accelerated helium ions. In a short irradiation of the kind that they employed, it was possible to transmute only about one part in 10^{11} of the target material, so that the total amount of californium formed and still present at the end of the irradiation was of the order of 10^{-10} moles or 10^{5} atoms. After the difficult and time-consuming chemical separations, the amount had dwindled by loss and decay to only a few thousand atoms. However, the decay characteristics, alpha energy and half-life, could be determined precisely. By virtue of the chemistry employed in the isolation, and the fact that the measured alpha-decay properties were those predicted, the new activity could be assigned unambiguously to an isotope of element 98. And this with the measurement of a *few thousand atoms*.

There are other consequences of the precision inherent in alpha-decay measurements. A great number of nuclides in the heavy-element region are joined in alpha-decay chains. By measuring the energies, one has an accurate thermodynamic scale relating the stability of different nuclei, and by mapping trends in stability, one not only learns something of nuclear structure but may also predict properties of unknown nuclei by interpolation and extrapolation.

Quite obviously alpha-particle measurement, wherever applicable, provides an excellent analytical tool. Such substances as plutonium, although avail-

able in macroscopic amounts, are often measured by their alpha particles rather than chemically because of the health hazard involved in working with chemically measurable quantities. Furthermore, the sensitivity of the radiometric method makes possible analytical work on concentrations far too low to yield to other methods.

Detection of Alpha Particles

The most common methods for measuring nuclear radiation employ the ionization produced in a gas by the particles themselves if charged or by secondary charged particles produced by the primary radiation or particles. The feature that distinguishes alpha particles from beta particles and gamma rays is the difference in density of ionization which they produce.

An alpha particle of 5 Mev ionizes so heavily that in a chamber only 5 cm deep and filled with air at atmospheric pressure, it will expend its entire energy and come to rest. On the other hand, a beta particle of 1 Mev will give up only about 1% of its energy, or 0.01 Mev, in the same chamber, and the average ionization caused by gamma-rays is considerably less.

The ionization produced by an alpha-particle is such that, by collecting the ions formed between a pair of electrodes, the pulse obtained is sufficient to measure by direct amplification. With an electronic cut-off to select pulses only above a certain size, it is possible to count alpha particles in the presence of a considerable amount of beta and gamma radiation.

For many purposes, an instrument that counts all alpha particles and distinguishes them only from other types of radiation is adequate. As mentioned previously, the measurements which distinguish different alpha emitters are of considerable importance in the present discussion. A method of historical interest and still useful is the determination of the range of an alpha particle (*4*).

As pointed out, an alpha particle has a range of only a few centimeters in air, and because of its high momentum compared with that of electrons, it does not deviate from a straight path. Since alpha particles of a particular nucleus are homogeneous (or fall into groups which are homogeneous), each may be distingushed by a discrete range, which is related to its energy. For many years this was the common method of relating energies, and much of the older work was reported in terms of *ranges* rather than *energies*.

The absolute method of energy determination employs a large magnet as an *alpha-ray spectrometer* (*5*). Its resolution is high, but strong sources are required. The energies of a number of natural alpha emitters have been determined to within 0.1%, and these serve as standards for comparative methods of energy determination. Alpha-ray spectrometry has the severe limitation that, for much of the work done with artificially produced alpha emitters, insufficient quantities can be prepared.

A powerful method for accomplishing much of what a magnetic spectrometer can do in energy resolution has been developed in form of an instrument called an *alpha-pulse analyzer* (*6*). In addition to this highly desirable quality of energy determination, it can perform spectrometry on sources a thousandfold weaker than that needed for the magnetic method.

The pulse analyzer measures total ionization produced by complete absorption of the alpha particle in a large ionization chamber and, since the ionization appears to be proportional to the alpha energy in the energy range of interest, it is possible to measure energies after calibration of the instrument. The instrument operates as a multichannel discriminator in which a pulse drawn from the ionization chamber is amplified linearly and appears

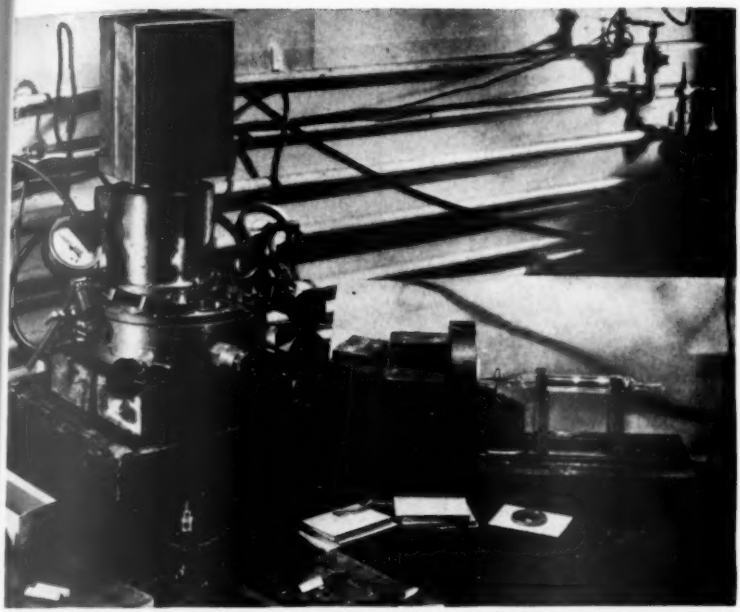
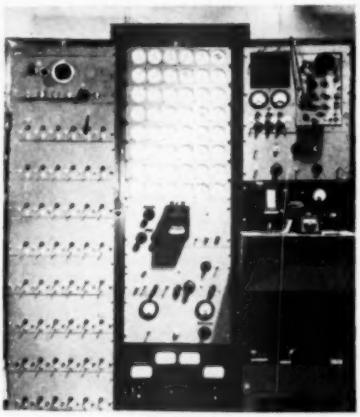


FIG. 1. Ion chamber and 48-channel pulse analyzer for alpha-particle measurements

(ABOVE) Ionization chamber and preamplifier. Knobs operate air lock and turntable for introducing samples without disturbing gas mixture in the chamber. To the right of the chamber can be seen a proportional counter used in conjunction with the multichannel discriminator to analyze soft gamma-rays and X-rays

(RIGHT) Operating and recording panel for multichannel-discriminator circuits. For a typical setting of controls, an alpha-particle peak has a width at half maximum of three registers (see Figs. 2 and 3)



as a count on a register driven by the channel sensitive to a particular small energy band.

Figure 1 is a photograph of a 48-channel unit in the University of California Radiation Laboratory.

Alpha-particle pulse analyses are shown in plots of experimental data in Figs. 2 and 3. Figure 2 is the U^{230} series, an artificially produced radioactive series which is collateral to the uranium-radium family and joins this family at Po^{214} (RaC'). Figure 3 shows the three alpha groups of the isotope of the recently discovered element 97, Bk^{243} (berkelium) (7). The positions of the peaks correspond to energy values

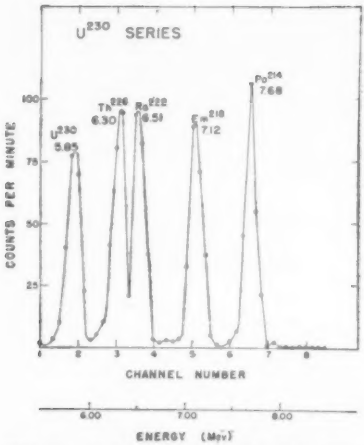


FIG. 2. Alpha-particle peaks of the U^{230} radioactive series collateral to the uranium-radium series. Gain and bias controls set to encompass band of about 3-Mev energy over the 48 channels ("Channel Number" refers to row of registers each with six channels). Since this illustration was made, the width of peaks has been sharpened considerably

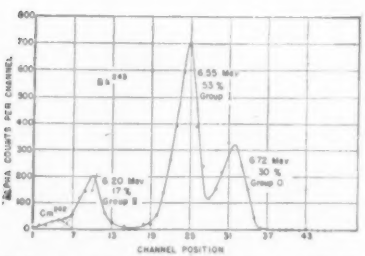


FIG. 3. Alpha-particle spectrum of Bk^{242} obtained with a control setting to spread the peaks. A band of alpha energy of only about 1 Mev is covered by the 48 channels

while the area under each peak represents the intensity of the activity. The sensitivity of this technique may be illustrated by the fact that, under favorable conditions (no nearby peaks), an alpha emitter may be identified with only 0.001 alpha disintegration per second available.

Another marked advantage of the alpha-pulse analyzer is the speed of measurement, which is of paramount importance for measurement of the many short-lived alpha emitters produced with high-energy particles. Sometimes twenty different alpha groups may be present in one sample from several decay series, with some groups growing and others decaying; nevertheless, the alpha-pulse analyzer measures all events simultaneously and, from a series of photographs of the register dials, one may dissect the complex mixture (*8*).

Aside from distinctive energies, the alpha-decay process lends itself to some special tricks in helping to identify the nuclei involved. One of these will be mentioned. In conserving momentum in the alpha-decay process, the residual nucleus acquires sufficient recoil energy to remove it from its mounting and propel it away. The collection of the *recoils* on another plate serves as a physical method of separating the alpha-decay daughters. If the identity of either the parent or the daughter is known, the other is fixed through the genetic relationship. This technique has been particularly useful in separating complex mixtures, for example, in determining a beta-emitting daughter of an alpha emitter or in showing the order of sequence of a family of alpha emitters.

Systematics of Alpha Energies

As previously stated, alpha-decay energies fall into a pattern that allows one to predict values for unknown species and, in general, gives a coherent picture of nuclear stability in the heavy-element region. Perhaps the best way to visualize the factors underlying the observed trends is to synthesize a thermodynamic surface in which the nuclei, lying on a rectangular coordinate system showing atomic number and mass number, are raised distances proportional to their mass defects or some

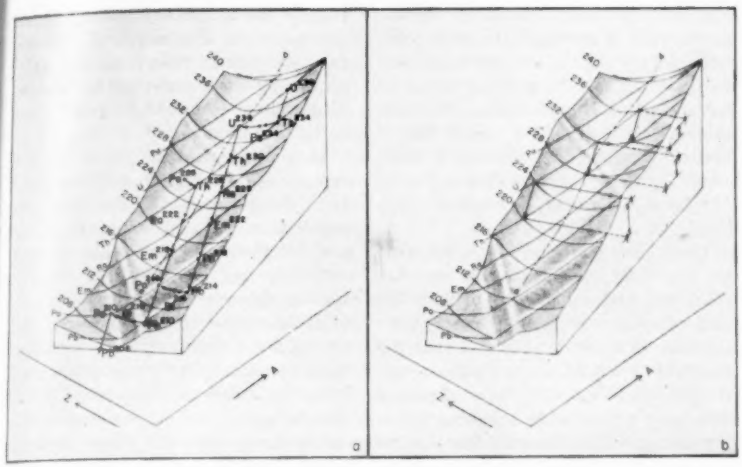


FIG. 4. Energy surface of heavy-element region, a schematic representation of relative stability of different nuclei. Vertical axis is some function of the mass or mass defect. (*a*) Energy surface with parts of uranium decay series with one of its collateral members. (*b*) Projections show increase in alpha energy with decrease in mass number for uranium alpha emitters

other function related to the total binding energy.

An idealized sketch of such an *energy surface* is shown as Fig. 4*a* in which certain proportions have been exaggerated for purposes of emphasis. It is also desirable for present purposes to normalize the sawtooth displacements between nuclei with odd and even numbers of nucleons; this is justifiable since alpha decay proceeds between nuclei of the same type. The sections of the surface at constant mass number are, for the most part, parabolic because they are derived from the semi-empirical and statistical treatment of nuclear binding energies (*9*). The line *ab* along the bottom of the valley joins nuclei of maximum stability for each value of *A* (mass number) and is termed the *line of stability*.

Fig. 4*a* shows the position of the uranium radioactive family and one of its artificially produced collateral chains (*8*). The alpha-decay steps proceed in a direction skew to the that of the valley and will be recognized by the change in mass number and atomic number, while the beta-decay steps go down the slope of the valley along contours of constant *A*. The reason why some of the nuclei on the slope of the valley are beta stable and others are not is not apparent from this energy surface because the *odd* and *even* variations which come into the beta-decay process have been ironed out. The point to be shown with these decay chains is that alpha decay cuts across the direction of the valley tending to produce more beta-unstable nuclei which then reach beta stability by progressing toward the line of stability.

One way to correlate alpha energies graphically is to compare the isotopes of each element (*10*, *11*, *12*). In Fig. 4*b*, alpha energies are considered for a sequence of isotopes of an element (uranium), and it is seen that decreasing mass numbers are accompanied by increasing alpha energies, as shown by the projections. This situation applies as

long as the sections of the energy surface at constant A are approximately parabolic and the slope of the surface parallel to the direction of the valley does not have marked irregularities. As mentioned, this results in a useful way of correlating alpha-decay data by plotting the alpha energy against the mass number for each element, as has been done in Fig. 5.

If we focus attention for the moment on the heavier elements, we see that the isotopes of each element define a line indicating increase in alpha energy with decrease in mass number and that the lines of the different elements are roughly parallel. This type of plot is extremely sensitive to irregularities in the energy surface, and the fact that no isotopes are out of order in the sequence and no lines cross bespeaks a high degree of regularity of the energy surface in this region. Probably when data are known more accurately, the lines will be even more regular.

As one possible source of error, it should be recognized that the energies plotted are total decay energies and if the observed alpha groups should be in cascade with gamma rays, the decay energy should be corrected upward. For two such cases in which this condition has been recognized (U^{235} and Am^{241}), the corrections have been made, and it is almost certain that others, unrecognized, exist. Three of those which are suspected are Pu^{239}, U^{233}, and Ra^{223}.

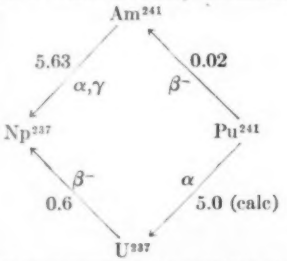
From the curves of Fig. 5, it is possible to estimate energies of unknown species and, as will be shown, the half-lives may be calculated from the energies. From these curves, it will be seen that the alpha energy of U^{236} must be very close to 5.5 Mev. As another example, if we bombard uranium with high-energy alpha particles and find a new plutonium alpha emitter of 6.5 Mev, we may be fairly sure that it is Pu^{232} and not Pu^{235}. With extrapolation of the trends and some judicious guesses as to the slopes of the new curves, it was possible to predict rather accurately the energies for the isotopes of the new elements berkelium (*13*) and californium (*3*).

If we now look at the lighter elements represented in Fig. 5, a sharp break from the regularity of the heavy elements is noted. Polonium, for example, behaves as do the other elements only between Po^{218} and Po^{212}, but with further decrease in mass number, the alpha energy drops precipitously and, at still lower mass numbers, turns once more upward. Closer examination will show that bismuth and astatine exhibit this behavior, and other elements definitely do so although there are large segments of the curves missing.

The reasons behind these sweeping changes in slope may be visualized from the lower part of the energy surface, Fig. 4. Here, it is seen that there are two major irregularities, one of which is a depression of the surface below neutron number 128. Viewed from the opposite point of vantage, the energy surface rises abruptly above the closed shell of 126 neutrons. Thus Po^{212} with 128 neutrons decays to Pb^{208} (126 neutrons) with corresponding great alpha energy, but Po^{210} (126 neutrons) is in the depressed area and, therefore, has a much lower alpha energy. At still lower mass numbers, the surface again resumes its valley-like structure and the alpha-energies begin to climb again. This break below 128 neutrons occurs with bismuth and astatine as well. It also occurs for francium and emanation since, although the isotopes defining the peak have not yet been seen, abnormally low alpha energies have been prepared at low mass numbers showing that a peak must exist (*14*).

If one is cognizant of the inversion of alpha energies in the region of 126 neutrons, it is not too difficult to make predictions from the regularities.

Another general method of estimating decay energies makes use of cyclical decay sequences consisting of beta- and alpha-decay processes and other energetically related processes. For example, we may wish to calculate the alpha energy of Pu^{241} whose alpha particle, although not observed directly, was inferred from the growth of U^{237}, the decay product. The known pertinent data are that Pu^{241} decays by β^--emission of low energy to Am^{241}, which in turn decays to Np^{237} through emission of alpha particles of 5.48 Mev followed by 60 kev of γ-radiation. Also, U^{237} decays to Np^{237} by β^--emission with 0.5–0.7 Mev decay energy. Some of these data, such as the decay energies of Am^{241} and U^{237}, will probably be altered but perhaps by less than 100 kev. One may then set up the following cycle of decay energies, three of the four legs of which are known and the fourth of which is readily calculated:

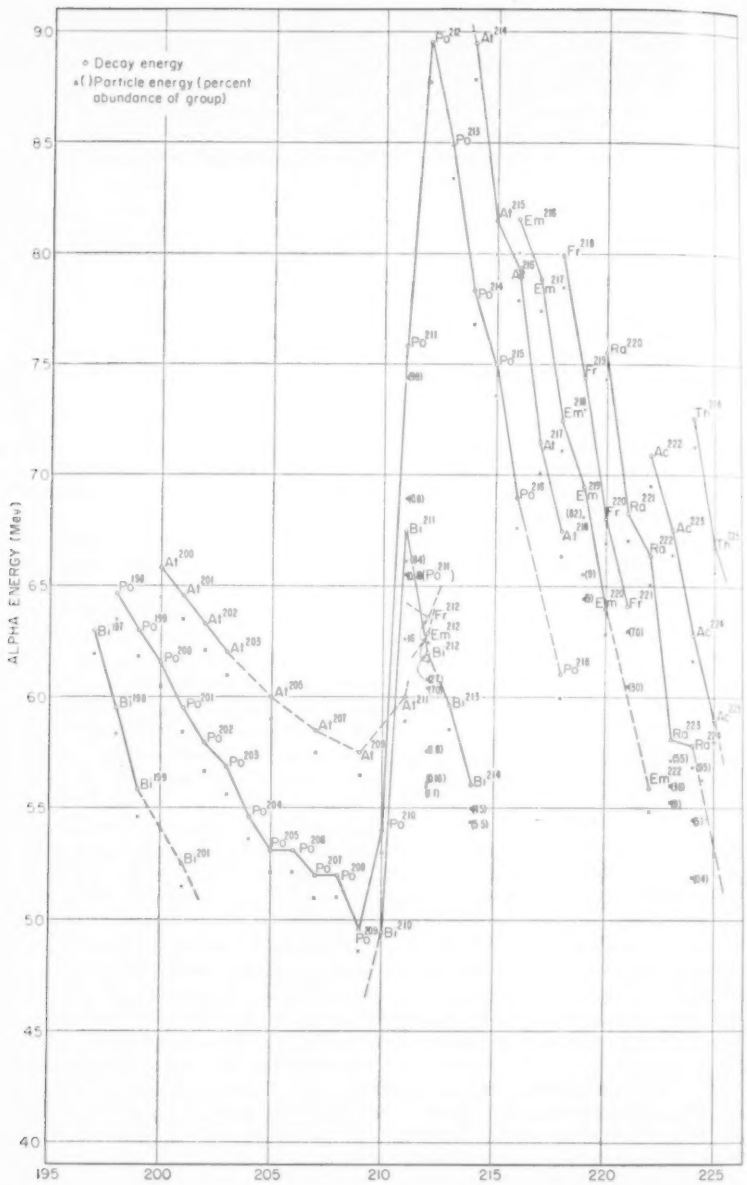


There are a number of variations of this type of calculation, some of which include more elaborate decay cycles, others contain measured or calculated neutron binding energies. It is, in fact, through such data as well as the experimentally determined decay energies that one can construct a reasonably accurate energy surface as shown in Fig. 4.

In all of the regularities discussed so far, the alpha energies are taken to be the total transition energies; that is, the alpha-particle energy, together with the recoil energy in each case, is assumed to represent the transition from the ground state of the parent to the ground state of the daughter nucleus. (Two exceptions have been mentioned earlier.) It has, in the past, been tacitly assumed that the alpha particle measured is invariably that of the ground-state transition, a logical consequence of the quantitative treatment of the alpha-decay process which places a great deal of emphasis on energy as determinative of the half-life.

On this basis, an alpha particle that does not have the maximum energy would compete poorly with one that does (the ground-state transition), and such lower-energy alpha particles would be found in low abundance or not at all. Nevertheless, among the natural radioactivities, there are a number of well-known cases of alpha-particle "fine structure," an unfortunate term applied to the possession of alpha groups other than that of the ground-state transition. Any low-energy groups would, of course, be followed by gamma radiation to make up the full decay energy.

Recent observations are tending to show that multiple alpha groups may be much more common than had been supposed, and that in some cases the ground-state transition may be seen with difficulty or not at all. One such case is that of the well-known U^{235}. The previously measured alpha particle of 4.4 Mev was the only one that had been noted. However, the availability of U^{235} highly separated from other uranium isotopes has shown up the ground-state transition of some 180-kev higher energy, but in low abundance ($\sim$10%) as compared with the lower energy groups (*12*). This corrected energy for U^{235} has been used in Fig. 5, and Am^{241} has been treated similarly. It is tempting to assume that such isotopes as Pu^{239}, U^{233}, and Ra^{223} have not exhibited their ground-state transitions in view of their misalignment in Fig. 5, but perhaps a few irregularities


○ Decay energy
▲( ) Particle energy (percent abundance of group)
ALPHA ENERGY (Mev)
90
85
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45
40
195
200
205
210
215
220
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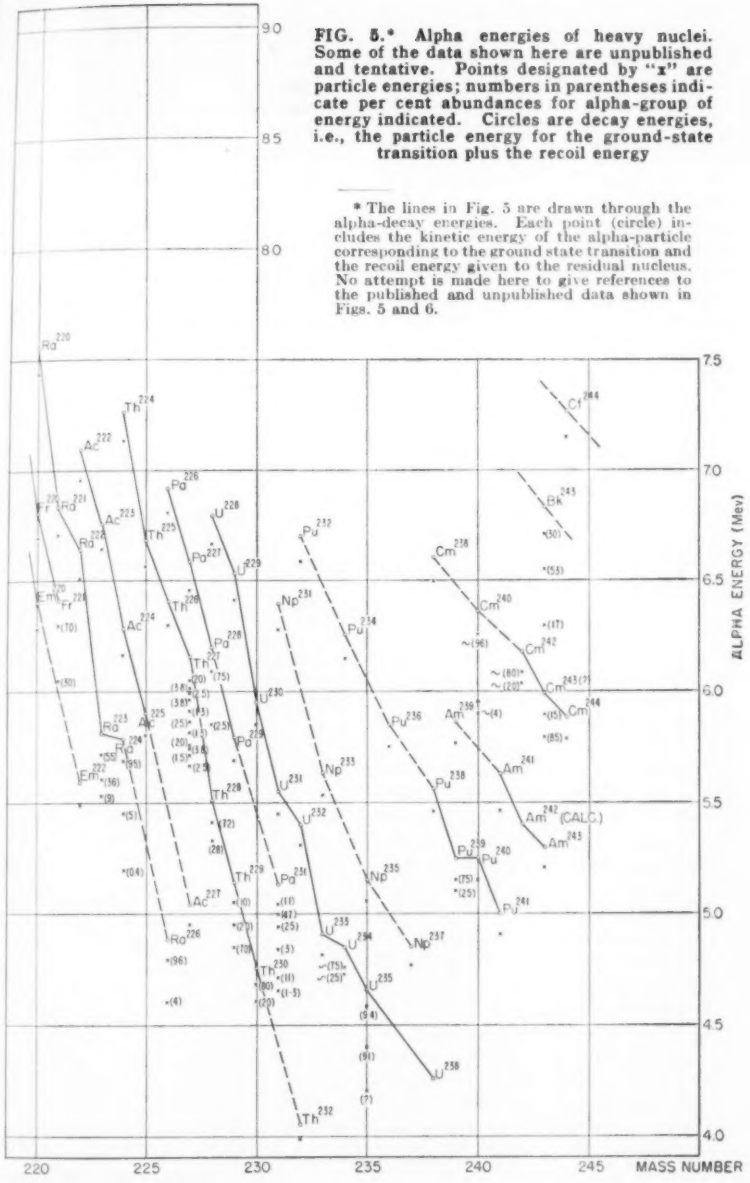


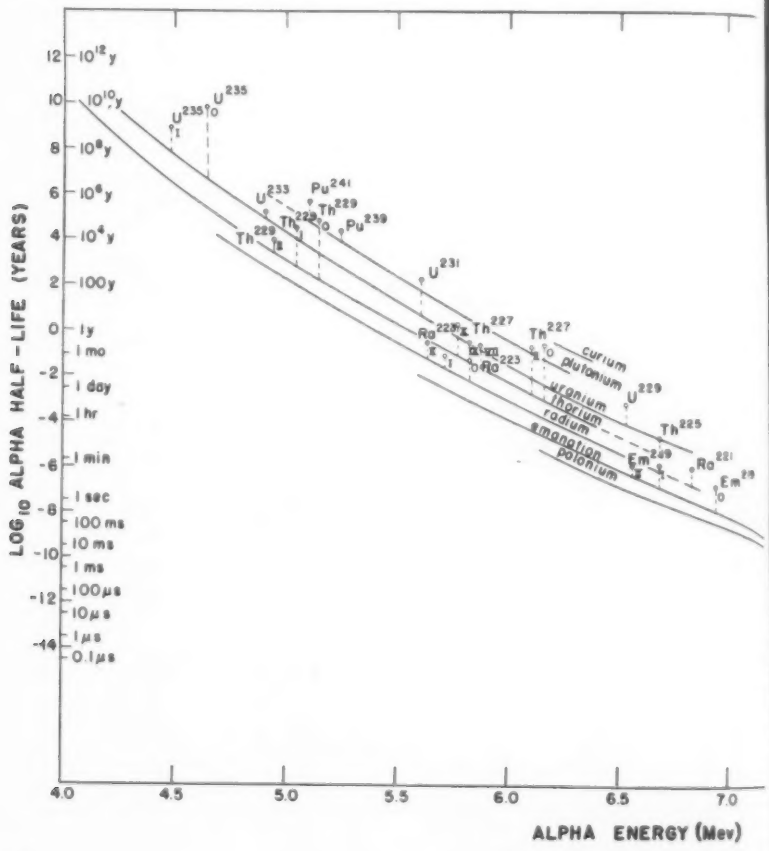
FIG. 5.* Alpha energies of heavy nuclei. Some of the data shown here are unpublished and tentative. Points designated by "x" are particle energies; numbers in parentheses indicate per cent abundances for alpha-group of energy indicated. Circles are decay energies, i.e., the particle energy for the ground-state transition plus the recoil energy

* The lines in Fig. 5 are drawn through the alpha-decay energies. Each point (circle) includes the kinetic energy of the alpha-particle corresponding to the ground state transition and the recoil energy given to the residual nucleus. No attempt is made here to give references to the published and unpublished data shown in Figs. 5 and 6.

do exist. We shall examine the reasons for alpha-decay fine structure in the following discussion of alpha-decay half-lives, where it will be seen that the occurrence of this phenomenon gives us some new hints on the nature of the alpha-emission process.

In discussing the behavior of alpha energies of heavy elements around the closed shell of 126 neutrons, it is of interest to note that an analogous situation with regard to 82 neutrons is apparently responsible for an island of alpha radioactivity in the region of the rare-earth elements (*15*). The decay energy toward alpha emission in this section of the periodic table is undoubtedly positive, but just low enough so that half-lives are out of the range of measurement. However, the added energy obtained for nuclei with 84 neutrons causes the alpha-radioactivity to appear.

It has long been noted that Sm^{144} (with 84 neutrons) is missing in natural samarium, although it must be beta stable and, therefore, is probably an alpha emitter. The sizable group of



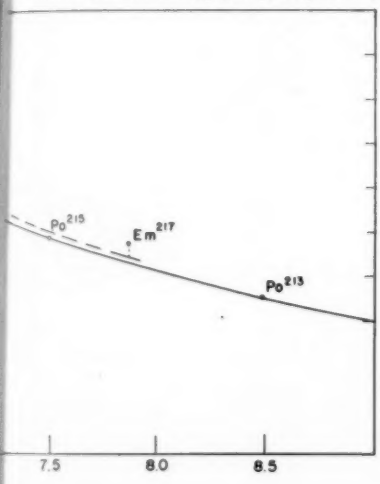
alpha emitters prepared artificially (*15*) in elements above samarium are probably analogous to the elements above polonium, although no definite mass number assignments have been made.

Alpha-decay Half-lives and Quantitative Aspects of the Theory

One of the most apparent features of the alpha-decay process is the wide range of half-lives encountered. Ordinary thorium (Th^{232}) with a 4.0-Mev alpha particle has a half-life of 1.4×10^{10} years, while one of its decay products ThC′ (Po^{212}) decays with a half-life of only 0.3 microsecond and gives off an 8.8-Mev alpha particle.

It was recognized early that there exists a relationship between decay constant and decay energy, but it remained for the quantum mechanical treatment of the process to reconcile the difference in decay constant of a factor of 10^{20} with difference in decay-energy of only about a factor of two. This spectacular application of quantum mechanics to a nuclear process explained the long-standing riddle whereby the alpha particle leaves the nucleus through a potential barrier several times higher than the energy of the alpha-particle.

FIG. 6. Relation between alpha energy and half-life for the EVEN-EVEN nuclei. The lines are calculated from alpha-decay theory; points are experimental. Subscripts "O" and "I" following the symbol indicate the ground-state transition and that of a lower-energy group, respectively



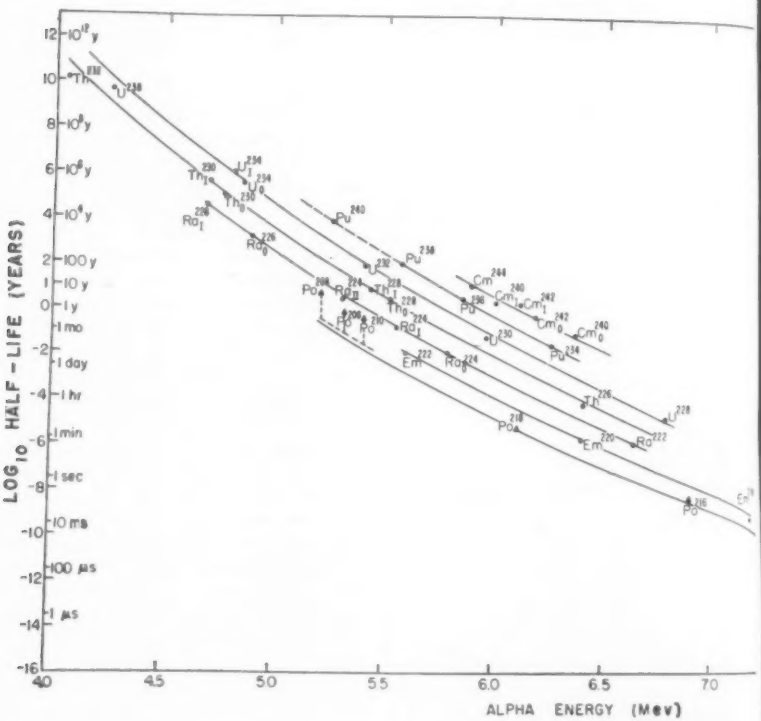
The rate of barrier penetration is extremely sensitive to the energy of the alpha-particle, thus accounting for the wide range of half-lives with relatively small change of alpha energy. Of lesser importance, because their ranges are more limited, are the parameters which control the height and thickness of the potential barrier. These are the nuclear charge and the nuclear radius, which operate to increase the barrier when there is an increase in charge or a decrease in radius.

The model that the alpha-decay theory is based on considers the alpha particle to exist as an entity within the nucleus of its decay product, and its rate of emission is governed by its emission velocity and the potential field of that nucleus. There is no provision in this *one-body model* for the assembly of the components of the alpha particle during or before its emission nor for any contribution of intermediate states on the potential field acting upon the alpha particle. Unfortunately, one of the parameters affecting the decay rate, the nuclear radius, cannot be evaluated independently with sufficient precision to point up any fine shortcomings of the simple model. On the other hand, there is good reason to believe that for the most part, nuclear dimensions are related in a simple fashion to the number of nucleons (A); therefore, the consistency of the function for nuclear radius calculated by assuming the validity of the theory at once serves as a guide both to the reasonableness of the model and the assumption for

nuclear radius. As will be seen, the *even-even* nuclei (even numbers of protons and neutrons) show remarkably consistent behavior.

Since the analytical expression relating decay constant, decay energy, atomic number and nuclear radius is unwieldy, it is more convenient to compare data with a series of curves derived from it. Such a family of curves for the even elements, explained in greater detail elsewhere (*12*, *16*, *17*, *18*), is shown in Fig. 6. Here, the alpha-energy and the logarithm of the half-life are the coordinates, while the atomic number is removed as an independent parameter by grouping data of constant Z (atomic number) in each curve. The reason the curves are smooth despite the independent variable r (nuclear radius) is that r is a function of A, the mass number, and the alpha energy changes monotonically with A according to Fig. 5 for most alpha emitters.

The curves in Fig. 6 have been calculated for the even Z elements using the function for radius, $r = 1.48 \times 10^{-13} A^{1/3}$ (cm). Experimental values for energy and half-life of the *even-even* nuclei have been entered. The agreement, in general, is quite remarkable, and probably cases of disagreement between experimental points and the calculated curves may yet be reconciled by more accurate measurements. One may infer, therefore, that either the simple model used for the alpha-decay

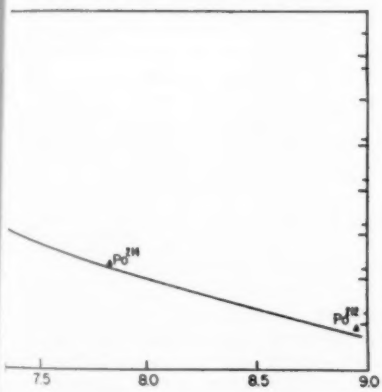


theory is justified or that any shortcomings are reflected in a uniform displacement of the values for nuclear radius.

Of particular interest are the cases of fine structure in alpha-decay for Th^{228}, Th^{230}, Ra^{226}, and others. Here it is seen that, in each case, both alpha groups fall on the curve. This means that each group obeys the theory as though it came from a different nucleus. In terms of abundances of the alpha groups, the lower-energy group is found in lower abundance (longer partial half-life). We shall see that nuclear types other than *even-even* show sharp differences from these regularities. A few other cases of fine structure in *even-even* nuclei are entered in Fig. 6, but the inaccuracies in measurement are such that there can be no statement made on the agreement with theory.

It will be noted in Fig. 6 that a few points (Po^{208}, Po^{210}, Em^{212}) lie well above their respective curves. They represent precisely those nuclei whose alpha energies create the sharp irregularities in Fig. 5, and these inversions of the normal trend were explained by closed-shell considerations. The increased stability of such nuclei might be expected to be accompanied by lower nuclear radii and, therefore, they should lie above the curves calculated on the basis of normal nuclear radii. An effective shrinkage of about 8% for Po^{210} would be required to explain its departure from the curve.

FIG. 7. Relation between alpha energy and half-life for the EVEN-ODD nuclei. The conventions used for Fig. 6 apply here



While the *even-even* nuclei appear to obey the one-body theory of alpha decay and with a few understandable exceptions have consistent nuclear radii, the behavior of all other types is found to be decidedly different. It is found that other types such as the *even-odd* nuclei have abnormally long half-lives and, since it is unreasonable to assume that this is an effect of nuclear radius, the conclusion is that the theory which describes the process accurately for *even-even* nuclei is not applicable to other types.

Figure 7 shows the half-life-versus-energy relationship for *even-odd* nuclei. Although not illustrated here, the same relationship for the other nuclear types is similar (*12*). The qualitative explanation (*12*) for this departure from the theory is that nuclei having an odd nucleon may not be considered as having a preformed alpha particle, but that, instead, time is required to assemble the components.

More precisely, the *ground-state transition* is considered to be prohibited since the alpha particle producing this transition must contain the odd nucleon. On this basis, one might expect lower-energy groups to be prominent since they should not be so highly prohibited. There is abundant evidence to support these views; indeed, as measurements are refined, it is becoming apparent that fine structure in alpha decay of such nuclei is the rule and that, in all probability, there are a number of alpha emitters for which the ground-state transitions have not yet been observed.

The important isotope U^{235} repre-

sents an interesting case in that the earlier-measured energy was lower than that which would be predicted according to Fig. 5 and that, in addition, fairly abundant gamma-rays indicated the existence of fine structure. With the recent availability of highly separated U^{235}, it became possible to examine its alpha particles without interference by groups from other isotopes, and a new group, presumably the ground-state transition, was found in ~10% abundance with ~180-kev higher energy than the group previously measured. The two groups may be seen in Fig. 7. It is apparent that the ground-state transition is highly prohibited, and has a half-life 1,000 times greater than would be expected for an *even-even* isotope of the same energy. The lower-energy group is much less highly forbidden, but its lower energy prevents U^{235} from decaying as rapidly as it otherwise would. It is worth noting that if the half-life of U^{235} were even a factor of two shorter than it is, there would be no usable quantity on earth today.

In examining the data of Fig. 7, it will be apparent that there is no uniform degree of departure from the curves of the *even-even* nuclei. On the average, however, such nuclei have about ten times as long half-lives as they would have if they behaved like the *even-even* nuclei. There is apparently a leveling effect by which lower-energy groups control the decay rate if the ground-state transition is high'y forbidden.

Prediction of Heavy-element Properties

The value of the correlations discussed above lie partly in the insight they afford into the structure of heavy nuclei and the theory of the alpha-decay process, but are also extremely useful in giving a rational basis for prediction of radioactive properties of unknown species.

As a guide to experimental work in this region, the observed regularities have been a powerful tool. This may be illustrated by the considerations making possible the discovery of californium, previously mentioned. By extrapolation of data such as those shown for curium and lower elements in Fig. 5 and checking by other empirical plots, it was possible to deduce that the alpha energy of Cf^{244} should lie in the range 7.1–7.3 Mev. As an *even-even* nucleus, one can show that its alpha-decay half-life should lie in the range 0.3–2 hours. Obviously, in looking for Cf^{244} from the bombardment of minute amounts of curium (Cm^{242}) with helium ions, this information is of great importance since it defines the duration of the bombardment and, more particularly, the time which may be spent on the chemical separation of the californium. When finally isolated, the alpha energy turned out to be 7.25 Mev and the half-life 45 minutes. It should be stated that Cf^{244} would also be expected to be unstable toward electron capture, and it was estimated that its half-life toward this mode of decay would be longer than that for alpha decay.

There are numerous other applications for the alpha-decay data which might be cited. One of these is in predicting which nuclei are beta stable. Often this property cannot be measured directly because of the alpha instability. However, one can usually produce a thermodynamic decay cycle in which the beta stability in question appears as the single unknown component and is, therefore, readily calculable.

In summary, we may say that important advances have been made in the last few years toward obtaining a complete picture of stability of heavy nuclei. The energy surface is visualized and the method for predicting the kinetics of the alpha-decay process for one nuclear type is fairly reliable. Nevertheless, there are many important

(*Continued on page 25*)

Distributed Beta Sources in Uniformly Absorbing Media—II*

As follow-up to the theoretical considerations published in Part I of this article, practical examples are given here in which the relations found for simple shapes of uniformly distributed beta sources are applied to cases involving more complicated geometries. These results may be useful also where non-uniform distribution exists in biological systems

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APPROXIMATE VALUES of dose and flux of beta particles may be computed if a beta-emitting isotope is uniformly distributed in a limited region of a medium, and if such a "distributed source" has one of a number of simple geometric shapes.

This fact was pointed out in the portion of this paper published earlier,† where it was stated that, for the purpose of these approximations, the absorption function for beta radiation is assumed to be exponential. Absorption coefficients were suggested for beta spectra of maximum energies between 0 and 1.7 Mev.

Practical Applications

In the series of examples that follow, the relations found for simple shapes are applied to examples of cases involving more complicated geometries.

The results of these computations may be useful in assaying the dose from beta particles originating from isotopes that are not continuously distributed in biological systems.

An attempt was made to derive an expression for the dose at a corner of a rectangular parallelepiped, since a knowledge of this relation would make it possible to determine the dose anywhere inside or outside *any* parallelepiped. This attempt had to be abandoned, however, because of the considerable mathematical difficulties encountered.

If the dose distribution in irregularly shaped configurations is to be determined by means of the data given in this paper, therefore, the shapes involved must be approximated by infinite slabs or planes, spheres, or, in certain cases, fractions of spherical shells. This has been done for some cases which will be discussed below.

It is felt that in the examples given the approximations used are good within 10 % or so. As will be shown, however, in some cases approximations based on the formulas derived in Part I are bound to result in considerable error, and may give meaningless results. Thus any further development must be performed with care.

1) Dose and count above an evaporating solution. Both the dose and flux above evaporating solutions of beta

* This article is based on work performed under Contract AT-30-1-GEN 70 for the Atomic Energy Commission.

† For Part I of this article, see NUCLEONICS 7, No. 1, 18 (1950). Figures 1–9 and all equations referred to in Part II appear in Part I.

emitters are of certain practical importance. A knowledge of the variation of dose is required in health physics when the hazard due to a drying solution is to be assayed. The flux is of interest in work performed with counters when maximum efficiency is sought by minimizing the mass associated with the activity to be measured.

If a solution of an isotope is evaporated uniformly, the activity per unit area, D, remains constant. For a slab of thickness $T(=t/\mu)$, $D = CT = Ct/\mu$; or $C = D\mu/t$. Thus the dose may be obtained by multiplying the curves in Fig. 4 by μ/t. The limiting case is obviously the one given by Eq. 14, the dose above the two dimensional source. Similarly the count will be given by multiplying Eq. 22 by μ/t and the limiting case by Eq. 19. Figures 10 and 11 show the resulting families of curves.

Besides the inherent error due to the approximate nature of the beta absorption function, a good many discrepancies are bound to arise if the curves in Figs. 10 and 11 are directly applied to conditions arising in practice. This is particularly true in the case of the count (Fig. 10).

In low-level activity work, a counting dish is usually placed in close proximity to an end-window counter. If the thickness of the window is expressed in terms of $1/\mu$, the counting rate should be obtained by reading off the ordinates in Fig. 10 that correspond to that value, because the window of the counter corresponds to the absorber involved in the curves of Fig. 10.

However, while absorption in the air gap between source and counter window will usually be negligible, scattering in the air may be significant unless the gap is very small, since, under practical conditions, the counting dish and the counter are usually of about equal diameter and this diameter in turn is likely to be small compared with the beta range in air. As a result, any betas

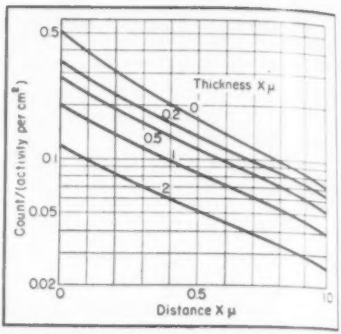

FIG 10. Flux above slabs of various thicknesses, all having a constant amount of activity per unit surface area

scattered out of the air gap will not be compensated for by betas scattered into it. This is bound to lower the observed counting rate from the theoretical value.

On the other hand, if the material of the counting dish is of a high atomic number, it will reflect betas more effectively into the counter if the thickness of the solution becomes comparable to $1/\mu$. Thus the theoretical value might be exceeded.

Scattering by the side walls of the dish and by the walls of the counter, and limited counter efficiency for particles incident at small angles, are other factors that may influence results drastically. An investigation is under way to determine the importance of these factors in practical cases.

Nevertheless, certain features of the situation may be considered largely independent of practical conditions. Thus it would appear that evaporation past a thickness of $0.1/\mu$ will not raise the counting rate significantly and that the relative improvement of counting rate, when a solution is evaporated, will be about the same no matter how thick the counting window. The latter follows from the fact that the curves in Fig. 10 are essentially parallel.

The curves of dose vs distance (Fig.

11) show that the depth-dose curves from beta applicators will be rather similar whether the active layer is thin or thick. For very thin sources, the dose near the surface may, of course, become very large, but the region in which it deviates significantly is quite small compared to $1/\mu$. Over most of the beta range, the change in dose that occurs if a source of $0.1/\mu$ thickness is "thinned" further is constant and amounts to less than 10%.

2) Integral dose due to I^{131} in the chick thyroid. For the purposes of this calculation the thyroid of a two-day-old chick may be represented by two spheres having diameters of 0.15 cm. Since the separation of the two spheres is several diameters, the dose contributed by one to the other is negligible. The dose due to gamma radiation may also be neglected.

To find the integral dose and the average dose in such a sphere, a numerical integration was performed. Each sphere was considered as being made up of spherical shells, and each shell was treated as if it received a uniform dose equal to the dose corresponding to the average of its two radii. These doses were multiplied by the volumes of the corresponding shells and added to find the integral dose. This was divided by the volume of the sphere to find the average dose.

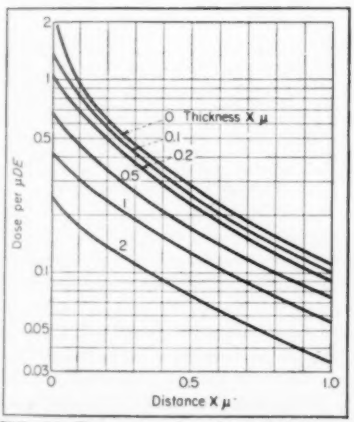

FIG. 11. Dose as a function of distance from slabs having various thicknesses and a constant amount of activity per unit surface area

I^{131} emits two beta rays having maximum energies of 605 and 250 kev. The former results from 86% of the disintegrations, the latter from the remaining 14%. The relative doses contributed in a continuum must be in the ratio of the products of energy and the branching ratio. Thus, in large distributed sources, 94% of the total dose is due to the 605-kev beta and 6% is due to the 250-kev beta. The dose in the chick thyroid will obviously be obtained by treating both betas separately and multiplying the resulting fractions of *CE* by 0.96 and 0.06, respectively.

The sphere was divided into ten shells. For the 605-kev beta, μ (as taken from Fig. 3) is 18 cm^2/gm, and a (the radius of the sphere expressed in multiples of $1/\mu$) is 1.3. For the 250-kev beta, $\mu = 63\ cm^2/gm$ and $a = 4.7$. By using these values and the procedure outlined, the integral dose was found to be 0.0010 *CE*; here *CE* expresses the integral dose from both betas in a cubic centimeter of continuum.

The dose in the chick thyroid varies from 0.76 *CE* at the center to 0.33 *CE* at the surface of each sphere, and the average dose is 0.55 *CE*. The average dose is very nearly the arithmetical mean of the surface and center doses.

3) I^{131} dose in mouse thyroid. From observations of mouse thyroids, it was decided that one lobe could be represented with reasonable accuracy by a figure of revolution having the cross section shown in Fig. 12. When this cross section is rotated upon its axis, the result is a volume enclosed by a circular cone and a spherical cap. The radius of the sphere was taken as 0.5 mm and the

length of the entire figure as 3.0 mm. As in the case of the chick thyroid, mutual irradiation of lobes and the dose from gamma radiation of I^{131} may be neglected.

The dose was computed in two different ways. The first method was a rough approximation made by means of overlapping spheres (Fig. 12*a*); the second, which was much more accurate, involved summation over spherical segments (Figs. 12*b* and 12*c*). This dual approach was chosen to get an idea of the validity of the first approximation since that method would appear to be the most logical to use with any irregularly shaped body.

In this approximation, the volume of the figure was computed and divided into five spheres. The first choice, depicted in Fig. 12*a*, was a poor one since it resulted in a very crude approximation of the shape of the apex of the figure. However, it was retained to get information on how critically the spheres had to be selected.

The dose at the center of each sphere was obtained by adding to the dose due to the sphere itself the dose contributed by the other spheres. Only the doses from immediate neighbors were found to be significant. The results of the computation are indicated by solid circles in Fig. 12*d*.

This figure shows also the result obtained by means of the more careful approximation which is outlined in Figs. 12*b* and 12*c*. Since the figure has rotational symmetry, it can be approximated by a sphere and sections of spherical shells (which have been called "segments," for the sake of brevity.) Here again the total volume of these bodies was made equal to the volume of the figure, but in this approximation overlapping of figures was avoided and the actual shape was approached much more closely. The result of this calculation is shown by the open circles in Fig. 12*d*.

To illustrate the sensitivity of the

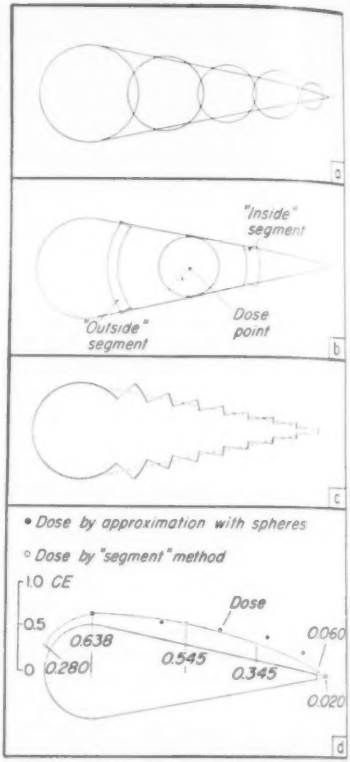

FIG. 12. Geometries used in treatment of a mouse thyroid: (*a*) Spheres used in spherical approximation drawn to scale. (*b*) "Segment" approximation for a point at the center. (*c*) "Segment" approximation for the center of the sphere at the left. (*d*) Axial dose in the thyroid lobe; points at 0.638 coincide

dose to curvatures near the apex, a dose value was computed for the curvature indicated which increased the dose by a factor of three. The value is quite low in either case, which indicates that the dose in the narrow isthmus connecting the two lobes must be negligibly small.

Comparison of the solid and open circles in Figure 12*d* suggests that an approximation involving overlapping spheres is quite adequate when done

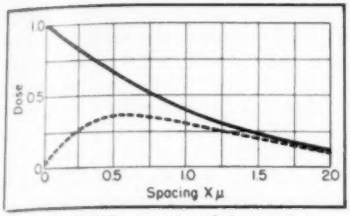

FIG. 13. Solid curve is minimum dose as function of lattice spacing. Dotted curve shows contribution of the eight lattice corners nearest to dose point

with some care, provided the spheres involved have a radius of the same order as the ones employed here ($0.1/\mu$ to $4/\mu$), and as long as the dose is not determined near the overlapping portions of the spheres. Presumably further, fairly reliable values of dose could have been obtained in planes that are at right angles to the axis of the figure and pass through the centers of the spheres. However, it was felt that the dose had been determined at a sufficient number of points to say that its average value is somewhat less than 40 % CE.

Dose in a Cubic Lattice

It is possible to employ the general approach presented here in the case of irregularly deposited isotopes. Cases of local concentration of activity can often be seen in autoradiographs where isotopes are concentrated in more or less distinct regions (as, for instance, iodine in follicles in the thyroid).

Assuming that these regions contain a certain average amount of activity and have an average spacing, it should be possible to derive a relation expressing the variation of dose that is likely to be encountered in such a system. Because of the considerable irregularities occurring in such "metabolic" distributions, the information obtained would probably be correct only within a factor of two or three, but this might be useful.

In cases where the dimensions of the total configuration are large compared with the beta range, the average dose must, of course, be equal to CE. If the activity is fairly well concentrated, the volume obtaining doses greater than CE will usually be small compared to the volume receiving doses less than CE (because of the approximately exponential absorption of betas), and for this reason it is the minimum dose that is of greatest interest.

As a first approximation, the activity may be thought to be concentrated in points which are arranged in a fixed three-dimensional lattice. For simplicity, a cubic lattice is chosen. The form factor introduced by other choices would be small compared to the other uncertainties of the procedure.

The problem may thus be restated as follows: If an activity C that is originally uniformly distributed in an infinite medium is equally concentrated in points located at the corners of a cubic lattice of spacing $U = u/\mu$, what will be the minimum dose in such a configuration?

Obviously this minimum dose will occur at each cube center and the activity per point must be $C \times U^3$.

The problem is thus reduced to a summation of doses from point sources as given by Eq. 4. The first eight points are, of course, at a distance $(u/2)\sqrt{3}$. It can be shown that all points will be on spherical shells of radii $(u/2)\sqrt{3+8n}$, with n going from zero to infinity. However, the number of points on each shell is a complicated function of the radius. Thus, for the first ten shells, the numbers of points per shell are 8, 24, 24, 32, 48, 24, 48, 72, 24 and 56, respectively. The number of points per shell may be obtained from detailed examination of the geometry of the system. For the sake of brevity, this, as well as further particulars of the calculation, are omitted.

The result of the computation is given by the solid line in Fig. 13. As may be expected, the minimum dose approaches

CE at spacings that are small compared with the value of μ.

A further study of the problem revealed that virtually the same result would have been obtained if the cubical lattice had been approximated by the eight points nearest to the dose point and a continuous distribution minus a "spherical hole" that is concentric with the dose-point and has a radius such that the activity contained in it is equal to $8U^3C$, the activity in the eight points. In other words, in a cubical lattice, all but the eight points nearest the dose point may be replaced by a continuum. This was found to be true regardless of the value of u although the relative contribution of the eight nearest points is small for low values of μ, as shown by the dotted line in Fig. 13.

Since the exponential absorption function leads to values that are too high, at least at points which are far from the point source, there must be regions in Fig. 13 that represent a lower limit which is too high. Such a quantity, when given without further specifications, is meaningless. However, as pointed out previously, the dose from a small sphere (and hence also the dose from a point source) may be considered to be well approximated up to distances of the order of $1/\mu$. It will be seen from Fig. 13 that at $1/\mu$ most of the dose is due to the eight point sources and that the error, therefore, may be presumed to be small. At lower values of u, the dose due to the continuum becomes larger, but there the radius of the "hole" in the continuum becomes smaller than $1/\mu$, and fairly good agreement may again be expected. It is believed, therefore, that the curve is fairly reliable at least up to $u = 1/\mu$.

A practical application in this region may be found in cases where the spatial variations in the distribution of activity are short compared to the range.

In the treatment of leukemia, P^{32} is known to have a tendency to concentrate in the leukocyte. The question has arisen whether this concentration in the *mature* cell makes P^{32} a better isotope to use than some other beta emitter that is not taken up preferentially by the leukocyte.

Taking the number of leukocytes per cubic millimeter of blood to be 10,000, the spacing that would be required if the cells were placed in a simple cubic lattice is 0.0046 cm. The tabulation of absorption coefficients in Part I shows μ for P^{32} to be 0.004 cm²/mg. Hence, assuming unit density, $\mu = 4$ cm^{-1}. Thus with $U = 0.0046$ and $\mu = 4$ cm^{-1}, $u = 0.0184$. It will be seen from Fig. 13 that this represents a minimum dose in the configuration which is about 2% less than CE. Since the dotted curve in Fig. 13 has a low value at this point, this dose is mostly contributed by points that are farther away than the immediate neighbors. Therefore, if one of the sources at a corner of the lattice were removed, the dose at this point would differ little from the minimum dose, because most of the activity contributing to the dose is just about as far away as it is from a cube center.

Thus the dose contributed by the other leukocytes amounts to a few per cent less than CE, and the gain due to concentration of the activity in the white cells must be very nearly equal to the dose from the activity in the cell itself.

To estimate this quantity, it is necessary to make some further assumptions on the parameters of the system. No figure for the relative concentration of P^{32} in white cells and the other blood components was required in the calculations since, as shown, the dose is nearly CE throughout the medium even with total concentration of the isotope in the center of the white cells.

To get a reasonable upper limit of the dose likely to occur in an individual leukocyte from the P^{32} absorbed in it, it will be assumed that the relative con-

centration of the isotope in such a cell is 25 times as high as in the rest of the blood. This value is higher than the experimentally determined concentration factor.* Since the radius of the leukocyte is quite small compared to $1/\mu$, the dose in such a small sphere will vary from aCE at the center to $aCE/2$ at the surface if there is no concentration of the isotope. Taking concentration into account, these values will be $25aCE$ and $12.5aCE$, respectively.

If the leukocyte is approximated by a sphere of 5 micron radius, $a = \mu A = 5 \times 10^{-4} \times 4 = 2 \times 10^{-3}$, and the dose in an isolated white cell would thus vary from $0.05CE$ at the center to $0.025\,CE$ at the surface. Thus it may be stated that the gain due to any reasonable concentration of P^{32} must be negligible. This analysis has been performed only for the mature cell in serum and does not apply to other aspects of the treatment of leukemia with P^{32}, particularly processes taking place in the hematopoietic tissues.

The treatment presented here could be extended to the case of spherical sources in a cubical lattice to cover situations in which the diameter of the sources is of the same order of magnitude as their spacing. However, it is felt that in most cases arising in practice the approximation by means of point sources is sufficiently accurate.

* * *

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Alpha Radioactivity *(Continued from page 18)*

details which must yet be supplied; in particular, those data pertaining to the beta-decay processes leave much to be desired.

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Biological Syntheses of Radioisotope-Labeled Compounds

Living organisms growing in a suitable radioactive environment can form biochemical compounds that are difficult or impossible to prepare by chemical methods. The great variety of isotopically labeled compounds prepared by biosynthesis is noted in this progress report on the technique

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AT THE 1949 meeting of the Federation of American Societies for Experimental Biology, a report (*1*) was presented on the status of the biological syntheses of radioisotope-labeled compounds.* This paper is a supplement to that report. An attempt has been made here to review the significant developments that have occurred during the past year in connection with the biological synthesis method. A few other points of interest not reported in the 1949 status report are also noted. No general discussion has been attempted on the general procedures used in the biosyntheses of labeled compounds.

The information presented in this paper is divided into the following categories: labeled materials from plants, labeled materials from animals, labeled materials from microorganisms, and a tabulation of isotope-labeled compounds prepared biosynthetically and location of the work.

Reference to unpublished information and communications directed to the Isotopes Division are designated with a star(★).

LABELED MATERIALS FROM PLANTS

Gibbs *et al.*, Brookhaven National Laboratory, describe techniques for the preparation of C^{14}-labeled starch, sucrose, glucose and fructose using bean leaves. In the biosynthesis of radioactive starch, carbohydrate-depleted bean leaves were exposed to approximately 10 % $C^{14}O_2$ (700 μc activity) for 24 to 48 hr, in the presence of light (*2*). The labeled starch was extracted from the leaves with dilute perchloric acid (*3*). The starch was then precipitated with 20 % sodium chloride solution and iodine-potassium iodide reagent. After decomposing the starch-iodine complex with alcoholic sodium hydroxide, the liberated starch was reprecipitated with 95 % alcohol, filtered and washed with 60 %, 95 %, and absolute alcohol. The use of a fresh weight of approximately 5 gm of bean leaves yielded 10 mg of starch with a specific activity of 12.4 μc/mg.

In experiments described for the synthesis of glucose and fructose, the bean

* Report was made to the FASEB at a session sponsored by the Biology Branch, Division of Biology and Medicine, and the Isotopes Division, U. S. Atomic Energy Commission. Minutes of this session are available from the Isotopes Division, Oak Ridge, Tennessee.

leaves were photosynthesized in the presence of 2.8 mc of $C^{14}O_2$ and killed in 80% alcohol (*4*). The alcohol extract contained sucrose, glucose and fructose as well as other alcohol-soluble substances. This solution was extracted with ether, then passed through a separation column to remove polar compounds. The solution was made 1*N* by the addition of sulfuric acid and kept at 80° for 10 minutes. After hydrolysis, the sample was passed through the column again to remove the acid. Most of the glucose was crystallized from the mixture by the addition of carrier glucose and alcohol.

Fructose was separated from the glucose still remaining in the mother liquor by means of one-dimensional chromatograms (*5*). Phenol was used as the solvent. A one-inch strip of paper can separate as much as 0.3 mg of fructose from a similar amount of glucose. The use of several strips of paper permits the separation of mg amounts of a very pure, highly active fructose. The final product, as reported by Partridge, had a specific activity of 1.2 mc/mg of fructose. Radioactivity determinations made by the degradation of the fructose showed uniform labeling.

In the synthesis of C^{14}-labeled sucrose, the same procedure was followed as outlined above with the exception that the monosaccharides were fermented out, using the yeast *Saccharomyces globosus* (*6*). The yeast was centrifuged off and the supernatant sugar solution passed through the separation column. The solution was concentrated and the sucrose crystallized out by the addition of absolute alcohol.

Gibbs points out that sugars isolated from plants which have been photosynthesized in $C^{14}O_2$ for 1, 2, and 24-hr periods fixed radioactive carbon in all positions (*7*). In the photosynthesis of barley seedlings for 1 and 2-hr periods, most of the label (56%) was in carbons 1 and 6, while positions 3 and 4 contained the least amount of activity (15%). Positions 2 and 5 were intermediate (28%). This is an interesting observation, since the percentages of C^{14} activity demonstrated in carbons 1, 6, and 3, 4 are opposite to the results reported by Aronoff *et al.* (*8*).

Noggle, Oak Ridge National Laboratory, has isolated C^{14}-labeled glucose, fructose and sucrose from photosynthesizing green plants grown in an environment containing $C^{14}O_2$ (★). The biosynthetic methods have been developed to permit good yields of the sugars with high radioactivity content. The individual sugars were isolated by column separation.

The synthesis of the trisaccharide, raffinose, is also being completed by means of sugar beet leaves. The yield of the raffinose is low because it has been necessary to use a very small photosynthetic chamber. At the present time, work is being done on the development of a large chamber so that a greater number of sugar beet leaves can be used. In addition to this synthesis, Noggle has made a partial separation of carotenoid A and B. A small quantity of labeled carotenoid has been separated with a fair degree of purity. Phosphoglyceric acid, uniformly labeled with C^{14}, has also been biosynthesized. This group is starting a new project using yeast incubated in a substrate containing C^{14}-labeled acetate as a possible medium for the synthesis of labeled inosital.

Up to the present time, Scully, Argonne National Laboratory, has been almost exclusively interested in the culturing of higher plants on $C^{14}O_2$ diets. Currently this group is cooperating with several laboratories in the biosynthesis of special compounds. Vitamin B_{12} labeled with Co^{60} and rutin labeled with C^{14} are being prepared in collaboration with Abbott Laboratories, Chicago, Ill. The synthesis of opium alkaloids labeled with C^{14} is being carried out in associa-

tion with Eli Lilly & Co., Indianapolis, Ind. Scully has also been cooperating with the University of Chicago in the synthesis of C^{14}-labeled digitoxin and with Northwestern University, Evanston, Ill., in the preparation of C^{14}-labeled ascorbic acid. In addition, this group has prepared C^{14}-labeled nicotine in significant quantities.

One of the major problems considered by the Argonne group during the past year has been the completion of the design and all preliminary tests on a growth chamber for the culturing of higher plants. The chamber is constructed so that plants may be grown with only a 2° F temperature variation and with a 4% variation in humidity. This control over environmental conditions permits the duplication of plant biosynthesis whether on a short or long-term basis. This constancy also holds true when excised organs of animals are used. At the present time, animal biosynthesis work has not started, but it is anticipated before the end of the year.

Several different species of plants have been used in the program. Among those employed during the past year are alfalfa, sugar beet, tobacco, opium poppy and onion. Scully points out that buckwheat and soybean plants are also to be used. Experimentally, the plants were grown for periods sufficiently long to suspect that all the carbon compounds were labeled. To date, the plants have been exposed to two different atmospheres as far as the level of C^{14} activity is concerned. At one level, approximately 350 μc C^{14} per gm carbon was used; at the other, 1 mc C^{14} per gm carbon. The activities in the plant tissues at harvest are less than this since various sized plants and seedlings containing no C^{14} were used and grown for variable periods of time.

Small stock piles of a variety of materials have been collected for information purposes to determine the biochemical fractions which can be isolated. One very interesting problem noted by Scully is the work on an extraction flowsheet that will be capable of isolating the sugar, amino acid and organic acid fractions of representative systems.

Calvin and Benson have isolated sucrose labeled with C^{14} in their studies on the path of carbon in photosynthesis (*9*). The experimental procedure employed green algae grown in an atmosphere containing $C^{14}O_2$. These investigators were able to show that sucrose is the first free sugar to appear during photosynthesis. This disaccharide is apparently formed by the condensation of glucose-1-phosphate and fructose phosphate. The labeled sucrose was separated by means of paper chromatography. A series of these chromatograms were made from extracts of plants that had been photosynthesized for different periods of time.

Sweet-potato leaves have been used in the biosynthesis of C^{14}-labeled glucose, as reported by Dubbs (*10*). A simplified procedure based upon the fractionation scheme of Hassid, McCready and Rosenfels was used to isolate the C^{14}-labeled glucose (*11*). The starch extract yielded 69 mg of crystalline glucose with a specific activity of 0.25 μc/mg. The soluble sugar extract yielded 189 mg of labeled glucose with an activity of 0.027 μc/mg. Of the total C^{14} activity assimilated, 26% was accounted for in the starch and soluble sugar extracts.

The sweet-potato leaf was used because of the ease of maintaining a continuous leaf supply. For specific purposes of glucose preparation, other leaves are apparently superior. The sweet-potato leaf fixed 26% of the assimilated C^{14} activity as starch and soluble sugar, whereas Aronoff *et al.* (*12*) (using barley seedlings) reported 25% to 35%, Putnam *et al.* (*13*) (using tobacco leaves) reported 45% to 55%, and Livingston and Medes (*14*) (using the bean leaf) reported 90% fixation.

It is pertinent to note that preliminary runs carried out with $C^{14}O_2$ under the specific conditions of this experiment indicate an average of 0.27 mg $C^{14}O_2$ assimilated per mg dry weight of sweet potato leaf per 24-hr run. During a 10-hr run, 52% of this amount was assimilated, and for a 2-hr run, 12%. In every 24-hr run, a 98.8% to 99.6% assimilation of available $C^{14}O_2$ took place when it was not introduced in excess of the rate noted in the first sentence.

MacKay, Scripps Metabolic Clinic, Los Angeles, Calif., has prepared C^{14}-labeled glucose by photosynthesis (★), using techniques similar to those outlined by Putman *et al.* (*13*). However, a floral type of nicotiana was used instead of the Turkish tobacco leaves employed by Putman. The nicotiana leaves permit a direct synthesis of glucose without the formation of starch. A little better than 10% of the C^{14} used is extracted as labeled glucose of high specific activity.

Villee and Hastings (*15*) have successfully used Gibbs' procedure for the biosynthesis of labeled glucose (*16*). Baldwin (★), General Foods Corporation, Hoboken, N. J., is planning a similar biosynthesis.

Rapport, Tufts College Medical School (★), Boston, Mass., has indicated that he plans to prepare glucose fully labeled with C^{14} in accordance with the procedure of Putman *et al.* (*13*).

Bonner reports an experiment with C^{14} in which attempts were made to discover the nature of the 5 carbon-branch chain compound, betamethylcortonic acid which is a precursor of rubber (*17*). Acetate containing C^{14} in both carbon atoms was supplied to seedling and mature guayule plants. After a three-day period, the plants were harvested and an appropriate procedure used for obtaining the organic fraction containing the betamethylcortonic acid. Inactive carrier was added to the organic fraction to aid in the isolation of the active compound. The sample was then recrystallized. Radioactivity measurements made on the isolated sample showed that the molecule contained C^{14}.

Radioactive digitoxin has been prepared by Geiling *et al.* from the medicinal plant *Digitalis lanata*, grown in an atmosphere containing $C^{14}O_2$ (*18, 19, 20*). $C^{14}O_2$, in quantities varying from a total of 660–1,440 μc (180–300 μc/plant), was introduced in divided amounts into batches of digitalis plants grown for 4–6 weeks. The samples of the crystallized glycoside isolated from plants demonstrated an activity in the order of 15,000 cpm/mg to 25,000 cpm/mg of the drug.

McIntosh, University of Louisville Medical School, Louisville, Ky. has used photosynthesizing plants to fix C^{14} into morphine and other drugs (★). $C^{14}O_2$ was introduced into the medicinal plants in quantities of approximately 1 mc total activity for each group of 5–10 plants. The morphine was extracted and purified by chromatographic adsorption. The specific activity of the morphine separated was 1–5 μc per 10 mg. This investigator points out that the amount of C^{14} incorporated into the morphine molecule increased with the length of the photosynthetic exposure.

Turrell, University of California, Citrus Experiment Station, Riverside, Calif., has planned experiments for the isolation and identification of sulfur-containing amino acids synthesized by citrus plants (★). The proposed procedure requires the use of a small citrus tree supplied with S^{35} in the form of sulfuric acid. Sulfur-containing amino acids such as methionine, cystine, and cysteine are to be isolated by means of paper chromatography.

C^{14}-labeled alanine and aspartic acid have been formed under conditions of light and darkness in green algae grown in a medium containing C^{14} methyl-

labeled pyruvic acid (*21*). Lemon reports the ability of algae to form labeled compounds from the radioactive pyruvic acid was much greater in the light than in the dark. Under both conditions, most of the radioactivity appeared as a single compound in the lipid fraction obtained from the algae. Very little labeled sugar was formed in the light and none appeared under conditions of darkness.

Ceithaml and Vennesland have obtained C^{14}-labeled isocitric acid, by means of an enzyme preparation from parsley root (*22*). In this experiment, the reaction mixture containing the enzyme preparation was incubated in the presence of C^{14}-labeled sodium carbonate. Radioactivity determinations demonstrated C^{14} activity in the beta-carboxyl carbon of the isocitric acid. These investigators have also demonstrated that oxalacetic acid subjected to enzymatic decarboxylation by parsley root preparation in the presence of C^{14}-labeled sodium bicarbonate can incorporate this activity into the beta-carboxyl carbon of this molecule. The radioactivity demonstrated in this compound was reported as approximately 8,400 cpm.

The incubation of the parsley-root preparation with unlabeled pyruvate and malate in the presence of $C^{14}O_2$ results in the incorporation of the C^{14} activity in the organic acid fraction (*23*). The amount of C^{14} fixed in the acid fraction is proportional to the malate contained in the fraction. The reaction mixture was incubated for three hours after which time the acid fraction was extracted and measured for radioactivity. The amount of C^{14} fixed in such a synthesis is relatively small.

LABELED MATERIALS FROM ANIMALS

Villee and Hastings have prepared glucose labeled with C^{14} from glycogen produced by liver slices incubated with pyruvate and $C^{14}O_2$ in a potassium-enriched medium (*15*). The glycogen was separated from the reaction mixture by appropriate methods and hydrolyzed for 2 hours with sulfuric acid. The acid was removed by the addition of saturated barium hydroxide. Radioactivity determinations made on the glucose demonstrated that it was labeled on carbons 3 and 4.

Rapport has proposed the preparation of 3,4 C^{14}-labeled glycogen by injecting radioactive potassium bicarbonate into animals. The animal fixation experiments are patterned after the experiments with C^{13} described by Wood *et al.* (*24*), and with C^{14} by Shreeve *et al.* (*25*). The animals will be sacrificed and the liver glycogen prepared (*26*). The labeled glycogen (and glucose previously mentioned under plant synthesis) will subsequently be used to prepare labeled hexose esters and beta-phosphogluconate. The C^{14}-labeled hexoses are to be prepared from the labeled glycogen and incubated with dialyzed muscle extract. This investigator also proposes to prepare hexose esters from C^{14}-labeled glucose, using muscle extract plus adenosine triphosphate. The phosphogluconate labeled with C^{14} will be prepared from glucose-6-phosphate by mild oxidation with bromine.

Gould *et al.* have shown that acetate is metabolized directly in the synthesis of glycogen without previous combustion to CO_2 (*27*). The experimental procedure involved the use of rabbit liver slices which were incubated in the presence of C^{14} carboxyl-labeled acetate. Radioactivity determinations gave evidence to the acetate utilization in glycogen synthesis.

Mitchell and Day, Indiana University, Bloomington, Ind., plan to administer C^{14}-labeled glucose and C^{14}-

labeled glucosone to rats to determine the possible metabolic transformation of these materials to hexosamines (★). D-glucosone will be used in the biological synthesis of glycogen. Each animal will receive approximately 1 μc C^{14}. A portion of the isolated glycogen and hexosamine is to be chemically degraded to their appropriate reaction products for the determination of the occurrence and distribution of the C^{14} activity in these amines.

Borsook *et al.* have employed guinea pig liver homogenate incubated with C^{14}-labeled lysine to study the rate of incorporation of this amino acid into protein (*28*). The rate of incorporation of labeled lysine into the proteins of the whole homogenate is approximately the same as that observed *in vivo*. After a one-hour incubation at 38° C, approximately 0.15% of the lysine in the protein is labeled. This rate is 60 times faster than any hitherto reported data in whole homogenates for other amino acids. The rate of incorporation of labeled lysine into the proteins of the sedimented fraction is several times that in the whole homogenate under its most favorable conditions. Radioactivity determinations on the protein samples of the whole homogenate showed that all the activity was accounted for as labeled lysine.

Block has reported the biological preparation of labeled glutathione using liver homogenates incubated in the presence of C^{14} carboxyl-labeled glycine (*29*). A 100-mg sample gave 151 cpm as an infinitely thick sample after combustion to barium carbonate. Radioactivity determinations showed that the glutathione contained the C^{14} in the glycine moiety only.

C^{14}-labeled serine has been isolated from liver protein of the rat. Greenberg *et al.* (*30*) report the introduction of 1 mg and 1.3 mg quantities of methylene and carboxyl-labeled glycine with activities of 560,000 cpm/mg or 4.57 μc and 880,000 cpm/mg or 7.2 μc into two rats respectively. Approximately 1.5 gm of protein powder were then prepared from each liver by a method previously reported (*31*). Milligram portions of the protein were mixed with carrier serine and glycine. The mixtures were hydrolyzed, and the amino acid carriers reisolated, recrystallized repeatedly, and then converted into their derivatives. High concentrations of C^{14} activity were found in the serine, as well as in the glycine of the liver protein. The serine accounted for 35% to 43% and glycine 45% of the total C^{14} in the liver protein.

Winnick *et al.* have demonstrated C^{14} activity in the protein fraction isolated from rat liver homogenate incubated with C^{14}-labeled glycine (*32*). Incubation of the homogenate with C^{14} carboxyl-labeled glycine gave rise only to carboxyl-labeled serine (*31*). By means of the labeled glycine, the homogenate yields serine labeled on both alpha and beta carbons (*33*). Carrier experiments with acid-hydrolyzed proteins from either methylene or carboxyl-labeled glycine incubations have shown that about 60% of the C^{14} activity is due to glycine and 40% is due to serine (*34*).

Greenberg and Winnick obtained relatively high concentrations of C^{14} in amino acids isolated from proteins of the liver and intestines of rat carcass (*35*). Each of three 200-gm male rats were injected with 32 μc of C^{14} (4,000,000 cpm) contained in several portions over a 48-hour period. This amount of radioactivity was contained in 20 mg of the following compounds: methyl and carboxyl-labeled acetate and sodium bicarbonate. Inactive compounds sufficient to make the three doses equivalent were added in the case of the last two substances. The protein powders obtained from the liver and the intestine of each animal were hydrolyzed with acid and subjected to the carrier method of analysis (*31*). The labeled amino

acids prepared by this procedure were glutamic acid, aspartic acid, alanine, and arginine.

Springson has prepared C^{14}-labeled acetic and aspartic acids using a rat fed C^{14} methylene-labeled glycine (*36*). The activity of the glycine fed was 1,370,000 cpm. The experimental procedure required the isolation of acetyl-1-aminophenylbutyric acid from the excreted urine. This component was hydrolyzed and the resultant acetic acid obtained as a sulfate salt. Aspartic acid was isolated from the proteins of the internal organs of the animal and decarboxylated by ninhydrin. Data collected during this experiment demonstrates that both carbon atoms of the acetate were derived from the alpha carbon of the glycine. The radioactivity of this sample was 4,100 cpm. The aspartic acid showed an activity in the alpha and beta carbon atoms 2.5 times greater than that demonstrated in the carboxyl groups. The latter activity may have been derived from the respiratory CO_2. The aspartic acid gave a total count of 1,300 cpm.

Stekol, Lankenau Hospital Research Institute, Philadelphia, Pa., proposes to use rats and tissue slice preparations to prepare S^{35}-labeled methionine and cystine (★).

Miller and Bale have prepared C^{14}-labeled *L*-glutamic acid and aspartic acid from liver and plasma proteins of dogs fed lysine-e-C^{14} (*37*). The glutamic acid was isolated as the hydrochloride and the aspartic acid as the copper salt from the acid hydrolysates of their respective preparations. Both the glutamic and aspartic acids had highly significant amounts of C^{14} activity when compared to the *L*-lysine dihydrochloride isolated from the same tissue. Radioactivity determinations indicate that the alpha carbon of the glutamic acid is unlikely as the locus of the C^{14} activity. It was assumed that the most probable site of the C^{14} was the gamma carboxyl radical of the glutamic acid.

In the course of protein metabolism studies using lysine-e-C^{14} in the dog, Miller has isolated other basic amino acids from protein hydrolysates with the aid of the ion-exchange column (*38*). *L*-arginine was isolated as the monoflaviante and radioactivity measurements made. Inert *L*-lysine was added to "wash out" any possible contamination with *L*-lysine-e-C^{14}. The solution was then reprecipitated. The specific activity of the arginine was unchanged.

Studies have been made on the biosynthesis of porphyrins and serine in duck blood (★). Shemin, Columbia University, incubated red blood cells of the duck with labeled acetate. Samples of the porphyrins were degraded and each carbon isolated for radioactivity measurements. Labeled serine has also been isolated and degraded from both *in vitro* and *in vivo* systems.

Grinstein, Kamen and Moore have demonstrated the use of glycine in the biosynthesis of hemoglobin (*39*). Glycine labeled with C^{14} in the carboxyl position was fed to dogs after the erythrocyte volume had been reduced by exsanguination. A 100-mg quantity of the labeled glycine was divided into 3 doses and fed to the dog on separate days. The total radioactivity administered amounted to 5×10^7 cpm. No radioactivity was demonstrated in the protoporphyrin isolated from the blood of the animals. The globulin fraction obtained from the dog blood gave a maximum specific activity of approximately 25 cpm/mg.

Similar experiments have been carried out by Altman and Salomon with C^{14}-labeled glycine (*40, 41*). The biological materials used were spleen homogenates and bone-marrow homogenates.

Cytochrome C labeled with radioactive iron has been prepared by Beinert, and Maier-Leibnitz (*42*). Iron-depleted rats were given radioactive iron

(Fe^{59}) of high specific activity. The total amount of radioactivity administered was about 11 mg. The cytochrome C was isolated from heart and skeletal muscle tissue according to the method of Keilin and Hartree (*43*). The isolated hemoproteins showed an activity of 1.235 ± 9 cpm/mg of pure cytochrome C on a molecular weight basis of 13,000.

Karlsson and Barker have synthesized uric acid labeled in various positions (*44*). C^{14}-labeled compounds were administered to young pigeons 10 times at 1-hr intervals. It was found by using labeled formate that this molecule is the precursor of positions 2 and 8 of the urate molecule. Approximately 40% of the precursor activity was recovered by the uric acid, and 98.5% of the incorporated activity was found in the two ureide carbons. C^{14}-labeled sodium bicarbonate was shown to be the precursor mainly of position 6 of the uric acid. The yield of uric acid using the bicarbonate was relatively low with approximately 2.8% of the precursor activity being recovered; 75% of this activity was in the 6 carbon. C^{14} carboxyl-labeled glycine was found to be a precursor of position 4. The isotopic yield of the uric acid with this material was 16.8%. The 4 carbon of the urate molecule concentrated 87.5% of the available activity. Uric acid formed from administered C^{14} methylene-labeled glycine was almost completely saturated with the isotope in the 2, 4, 5 and 8 positions. Only 52% of the total activity in the uric acid molecule synthesized in this manner was in the 5 position

Kidder and Heinrich, Amherst University, Amherst, Mass., propose to study the formation of purines and pyrimidines (★) in mice and rats. Doses of sodium formate containing 1 to 4 μc of C^{14} will be administered to each animal. The individual purines and pyrimidines are to be isolated from tissue nucleic acids. Certain amino acids will also be prepared from isolated tissue proteins.

Wollman, National Institutes of Health, Bethesda, Md., plans to prepare radioactive adenine from separated cell particulates (★). The cells will be incubated with C^{14} carboxyl and methylene-labeled glycine in an appropriate medium. The labeled adenine will be separated by paper chromatography and radioactivity determinations made.

Nucleic acids tagged with radiophosphorus (P^{32}) have been isolated from rat liver and kidney tissue slices by Manin and Gruschow (*45*). The experimental procedure employed dried tissue slices which were placed in Krebs-Ringer bicarbonate solution. P^{32} was added to the solution in a concentration of about 1 μc/ml. The nucleic acid fraction was separated from the other constituents, weighed, and dissolved in alkali. Radioactivity measurement showed that the P^{32} was incorporated into the nucleic acid molecule.

Winzler, University of Southern California, Los Angeles, Calif., proposes the use of rat tissue slices incubated with a nutrient solution containing radioactive phosphate (P^{32}) for the isolation of nucleoproteins and phospholipids (★). The incubation period is to be carried out for about 5 hours. The reaction mixture will then be treated with trichloroacetic acid and the specific activity of the separated labeled compounds determined.

Valentine *et al.* have isolated samples of C^{14}-labeled allantoin from urine samples collected from a pigeon fed a diet containing C^{14} carboxyl-labeled glycine (*46*). The specific radioactivity of the samples collected increased gradually to a maximum on the tenth day. Determination of the positions of the radioactivity in the molecule was made by degrading the allantoin to glyoxylic acid and urea. C^{14} was found in the glyoxylic acid fraction corresponding to

carbons 4 and 5 of the allantoin molecule.

Weinhouse and Millington have shown that radioactive acetoacetate labeled predominently in the alpha position can be synthesized by means of C^{14} beta-labeled tyrosine incubated with rat-liver slices (*47*). The specific activity of the isolated samples was reported as a relative amount based on an assumed value of 100 for the labeled tyrosine. Radioactivity determinations carried out indicate that the C^{14} activity was concentrated predominently in the alpha carbon with no appreciable radioactivity being found in the beta and gamma carbons.

Coon and Gurin have made similar studies on the formation of acetoacetate in liver slices incubated with C^{14}-labeled leucine tagged separately in the beta and gamma positions (*48*). The acetoacetate isolated from this reaction mixture indicates that the beta and gamma carbons of the amino acid split off as a two carbon intermediate during the incubation process. This intermediate product is capable of condensing to form acetoacetate. The radioactive acetoacetate collected was predominantly labeled with C^{14} in the gamma carbon.

Rats injected with P^{32} will be employed to prepare radioactive phospholipids (★). Roth, Rutgers University, plans to inject rats with 10 μc each of P^{32}. After a six-hour period, the animals are to be sacrificed and the livers removed, minced under alcohol, and subsequently extracted with organic solvents. The activity of the phospholipid fractions are to be determined by means of dry samples.

Keller *et al.* have prepared labeled choline and creatine (*49*). Methionine labeled with C^{14} was fed to a rat for four days. The choline and creatine were isolated from the carcass of the animal as creatinine potassium picrate and choline chloroplatinate, respectively (*50*). Radioactivity measurements were carried out on the choline and creatine according to the procedure described by Melville, Rachele, and Keller (*51*). The C^{14} content of the isolated sample of choline chloroplatinate was 2.439×10^6 cpm/mmole; for the creatinine potassium picrate, the activity observed was 1.746×10^5 cpm/mmole. The activity of the C^{14} methyl-labeled methionine fed to the animal was 1.124×10^7 cpm/mmole.

Mackenzie and du Vigneaud have observed that radioactive formaldehyde is formed during the biological oxidation of the methyl group of C^{14}-labeled sarcosine (*52*). The formaldehyde was isolated as the dimedon derivative from the trichloroacetic acid filtrate of rat liver homogenate incubated with labeled sarcosine.

A unique departure from the usual synthetic environment is Zamecnik's use of the giant silk worm *Platysamia cecropia* for the purpose of synthesizing biologically radioactive silk (*53*). Since glycine and alanine are present in exceptional concentrations in fibrin, the protein of silk, the use of these C^{14}-tagged amino acids offers a possible approach to the biological preparation of a stable homogenous radioactive protein. Radioactive amino acid mixture in the amount of 0.05 cc was introduced into the silk worm giving a total activity of 27,000 cpm. The injection contained 0.013 mg of C^{14} carboxyl-labeled glycine with an activity of 18,000 cpm and 0.02 mg of C^{14} carboxyl-labeled alanine with an activity of 9,000 cpm.

Following injection of the radioactive mixture, the silkworm continued to feed normally for 24 hours. After this period, it began spinning its cocoon. To test the radioactivity of the silk, small pieces of cocoon were homogenized into tiny fragments in water. The suspension was precipitated in 10% trichloroacetic acid, washed with trichloroacetic acid, and hydrolyzed overnight with 6*N* hydrochloric acid. Duplicate

counts made on the barium carbonate precipitate gave 150 and 160 cpm/0.1 mmole barium carbonate. The radioactivity was shown to be present in the alpha-carboxyl group of some amino acid associated with the silk fibers.

LABELED MATERIALS OBTAINED FROM MICROORGANISMS

Wolochow *et al.* (*54*) have demonstrated that sucrose labeled with C^{14} can be synthesized enzymatically from its constituent monosaccharides by labeling a component part of the disaccharide with C^{14}. Radioactive sucrose tagged in the fructose moiety has been prepared by allowing C^{14}-labeled glucose-*l*-fructoside to be exchanged for fructose in the inactive sucrose molecule in the presence of an enzymatic extract from *Pseudomonas saccharophila*. Radioactive sucrose tagged in the glucose moiety can be prepared by allowing glucose-*l*-phosphate to react with inactive fructose in the presence of the same enzyme.

By hydrolyzing the synthetic radioactive sucrose preparations into their monosaccharide units, it was shown that in the first sample 90 ± 3% of the disaccharide activity resided in the fructose residue. There was less than 1% in the glucose residue. In the second sample, the glucose moiety contained 96 ± 3% of the activity. The C^{14} activity residing in the fructose unit was less than 1%.

By means of these synthetic procedures, 72% of the possible theoretical activity was demonstrated in the radioactive sucrose molecule when C^{14}-labeled glucose was used. With the C^{14}-labeled fructose, 76% of the possible theoretical activity was contained in the labeled sucrose molecule.

Bhat and Barker have isolated labeled acetic and butyric acids from enriched cultures of the bacterium *Clostridium lacto-acetophilum* in the presence of C^{14}-labeled sodium carbonate (*55*). The total activity used in the experiment was 10,600 cpm/mmole. The yield of the isolated acetate was 3.90 mmole/100 ml with a C^{14} activity of 1,350 cpm/mmole. The butyric acid isolated gave a yield of 4.29 mmole/100 ml with a specific activity of 1,650 cpm/mmole.

Using the bacterium *Clostridium acidi-urici*, Karlsson and Barker have prepared C^{14}-labeled acetic acid from various labeled substrates (*56*). Fermentation of 2,8 labeled uric acid by the bacterium-produced acetic acid labeled predominantly (95%) in the methyl position. The small amount of activity demonstrated in the carboxyl group must have been derived from the 5 carbon of the uric acid or from the $C^{14}O_2$ evolved.

Labeled acetic acid derived from the urate labeled on carbon 5 contained more C^{14} activity (72%) in the carboxyl group than in the methyl group. The activity in the carboxyl group in all probability was derived almost entirely from the 5 carbon of the uric acid. The activity of the methyl group must have been partially derived from the activity contained in the 2 and 8 positions of the urate.

Fermentation of methylene-labeled glycine produced acetic acid which contained three times as much activity in the carboxyl carbon as in the methyl carbon. Since no activity was present in the CO_2, all the observed activity in the acetic acid must have been derived directly from the glycine.

C^{14}-labeled acetic acid is to be prepared by Hanahan (★), Washington University. The procedure to be used in this synthesis was not indicated.

Krampitz, Western Reserve University, proposes to employ an enzyme preparation from the bacterium *Aerobacter aerogenes* for the enzymatic syn-

thesis of acetylmethylcarbinol (★). The enzyme preparation is to be used to ferment pyruvic acid-2-C^{14}. Another bacterium *E. coli*, grown in a culture containing C^{14} methyl-labeled acetic acid, will be used for the synthesis of succinic acid.

Foster *et al.* have synthesized labeled fumaric acid in high yields from C^{14}-labeled ethanol using the mold *Rhizopus nigricans* (*57*). C^{14} methyl-labeled ethanol and C^{14} carbinol-labeled ethanol were added to the nutrient medium. The yield of the labeled fumarate from the C^{14} methyl-labeled ethanol culture was 5.4 mg/ml. The yield of labeled fumarate from C^{14} carbinol-labeled ethanol was 5.2 mg/ml.

A small quantity of each kind of labeled fumarate was combusted to determine total radioactivity. Another quantity was degraded with acid permanganate to determine the positions of the labeled carbons. The fumaric acid formed from the C^{14} methyl-labeled ethanol contained the same specific activity in the methine carbon as that in the methyl group from the starting alcohol. The specific activities of the methine carbon and the carboxyl carbon of the fumarate were 3.6 and 0.07 cps/mg $BaCO_3$. The specific activity of the starting ethanol in the experiment was 1.83 cps/mg $BaCO_3$, and that of the isolated fumaric acid 2.18 cps/mg $BaCO_3$. This increase is accounted for by the entrance of labeled carbon dioxide into the initially nonradioactive carboxyls of the fumarate. The fumaric acid formed by using the C^{14}-carbinol-labeled ethanol contained no radioactivity in the methine carbon, but activity was abundant in the carboxyls. The specific activity of the fumarate was 1.2 cps/mg $BaCO_3$, and the activity was located entirely in the carboxyls. The specific activity of the starting radioactive alcohols used in the experiment was 1.67 cps/mg $BaCO_3$. The reduction in activity of this fumarate probably results from the dilution of the radioactive carboxyl groups with inactive carboxyl carbons.

The formation of fumaric acid by this method permits the biosynthesis of a valuable organic acid (*57*). This technique also provides the only feasible method of synthesizing methine-labeled maleic anhydride, a vital intermediate in the chemical synthesis of many suitable labeled ring-type organic compounds, including carcinogens.

The mold *Aspergillus niger* will be used as the experimental medium for the synthesis of labeled citric acid of high specific activity (★). Ochoa, New York University, plans to prepare labeled citric acid by supplying a growing culture of the mold with C^{14}-labeled sucrose.

Stadtman *et al.* have used the bacterium *Clostridium kluyveri* incubated in the presence of ethanol and C^{14} carboxyl-labeled butyric acid as a mechanism for the synthesis of caproic acid (*58*). The reaction proceeds by a condensation of a C_2 product with a C_4 product to give a C_6 compound. The specific activity of a sample of the labeled caproic acid prepared was 1,250 cpm/mmole. Essentially all the C^{14} in the caproic acid was present in the beta position.

The *Cl. kluyveri* was also used by Stadtman *et al.* in the fermentation of ethanol and carboxyl-labeled propionic acid for the synthesis of *n*-valerate and *n*-heptanoate. The valeric acid is formed similarly as caproic acid by a condensation of the carboxyl carbon of propionic acid with the methyl carbon of the alcohol.

The propionic acid-ethanol fermentation may be used as a simple and convenient method for the preparation of *n*-valeric acid labeled in various positions with carbon isotopes. The fermentation as described by Stadtman *et al.* gave a 69% yield of beta-labeled valeric acid. By fermenting unlabeled

propionic acid and ethanol in the presence of C^{14}-methyl-labeled acetic acid, alpha-labeled valeric acid can be obtained in good yield. Still other types of labeled valeric acid may be prepared by starting with alpha or beta-labeled propionic acid. Delta-labeled heptanoic acid is probably formed from beta-labeled valeric acid and ethanol by a further condensation.

The specific activity and yield of the sample of *n*-valerate prepared was 600,000 cpm/mmole. The yield of the *n*-heptanoate was 0.34 mmole/100 ml. The specific activity of this acid was 530,000 cpm/mmole.

C^{14}-labeled *n*-propanol was formed in significant amounts in the ethanol-propionic acid fermentation. The propanol was produced entirely by reduction of the C^{14} carboxyl-labeled propionic acid. The yield of the labeled *n*-propanol was 1.45 mmole/100 ml. The specific activity of the material was 590,000 cpm/mmole.

Lardy, Potter, and Burris have prepared C^{14}-labeled aspartic acid (*59*). Cells of *Lactobacillus arabinosus* were grown in the presence of C^{14}-labeled bicarbonate and 2 mg of biotin per ml. It was demonstrated that the cells of *L. arabinosus* fixed C^{14} activity from the bicarbonate in the reaction mixture into the cellular aspartic acid. The bacillus cells were almost totally unable to fix CO_2 when they were grown in a medium containing 0.05 mg of biotin per ml or less.

Friedburg and Webb have demonstrated C^{14} activity in the cell protein of *Torula utilis* (*60*). The cells of the yeast were incubated aerobically with C^{14} carboxyl-labeled glycine. The total activity of the labeled glycine used was 1,360 cps. The cell suspension was equivalent to 30 mg of protein. The incubation period was carried out for 45 min, after which time the protein was precipitated with trichloroacetic acid. The mixture was then washed in alcohol. The protein was suspended in a hot ether-alcohol mixture, collected on filter paper and weighed. The specific activity of the protein separated from the cell suspension averaged 0.66 cps/mg of protein.

GUIDE TO LABELED COMPOUNDS PREPARED BIOSYNTHETICALLY*

Compound; Isotope; Institution	*Status†*
1. **Acetic acid** (C^{14})	
Univ. of California	C(*55, 56*)
Calif. Inst. of Tech.	P‡
Univ. of Washington	P‡
Iowa State College	P‡
D. B. Sprinson (Columbia Univ.)	C(*36*)
2. **Acetoacetate** (C^{14})	
Univ. of Pennsylvania	C(*48*)
Temple Univ.	C(*47*)
3. **Acetylmethyl-carbinol** (C^{14})	
Western Reserve Univ.	P‡
4. **Adenine** (C^{14})	
Natl. Inst. of Health	P‡
5. **Adenosine triphosphate** (P^{32})	
Overly Biochemical Research Foundation	P‡
6. **Albumin** (I^{131})	
Univ. of Utah	P‡
Western Reserve Univ.	P‡

(*Continued on next page*)

* This tabulation is supplementary to the list of compounds included with the mimeographed report on the status of biological syntheses of radioisotope labeled compounds presented at the 1949 FASEB meeting.

† C = work completed; U = work underway; P = work proposed (see following footnote); numbers denote references in bibliography; star denotes unpublished information and communications directed to the Isotopes Division.

‡ Preparation indicated in Form AEC-313 "Application for Radioisotope Procurement," submitted to the Isotopes Division, Oak Ridge, Tennessee.

Compound; Isotope; Institution	*Status*
7. Alanine (C^{14})	
Univ. of California	C(*21,35*)
8. Alkaloids (C^{14})	
Univ. of Chicago	P‡
9. Allantoin (C^{14})	
Univ. of Pennsylvania	C(*46*)
10. Amino acids (S^{35})	
Harvard University	P‡
Amino acids (C^{14})	
Amherst College	P‡
Univ. of California	P‡
Univ. of Chicago	P‡
Mass. Gen. Hosp.	P‡
Oregon State College	P‡
Reed College	P‡
11. Antibodies (I^{131})	
Public Health Service	P‡
12. Arginine (C^{14})	
Univ. of California	C(*35*)
Univ. of Rochester	C(*38*)
13. Ascorbic acid (C^{14})	
Univ. of Pennsylvania	P‡
14. Aspartic acid (C^{14})	
Univ. of California	C(*21,35*)
Univ. of Rochester	C(*37*)
D. B. Sprinson (Columbia Univ.)	C(*36*)
Univ. of Wisconsin	C(*59*)
15. Betamethyl-cortonic acid (C^{14})	
Calif. Inst. of Tech.	C(*17*)
16. Biotin (C^{14})	
Cornell Univ. Med. School	C(*59*)
17. Butyric acid (C^{14})	
Univ. of California	C(*55*)
18. Caproic acid (C^{14})	
Univ. of California	C(*58*)
19. Carbohydrates (C^{14})	
Howard Univ.	P‡
20. Carnosine, beta alanine portion (C^{14})	
Univ. of Illinois	P‡
21. Carotene (C^{14})	
Univ. of So. Calif.	P‡
Oak Ridge Natl. Lab.	C(★)
22. Cholesterol (C^{14})	
Univ. of Chicago	P‡
Duke Univ.	P‡
Univ. of Oregon	P‡
Univ. of Utah	P‡
23. Choline (C^{14})	
Lankenau Hosp. Research Inst. (Temple Univ.)	P‡
Cornell Univ. Med. School	C(*49*)
24. Citric acid (C^{14})	
New York Univ.	P‡
Univ. of Wisconsin	P‡
25. Creatine (C^{14})	
Lankenau Hosp. Research Inst. (Temple Univ.)	P‡
Cornell Univ. Med. School	C(*49,50*)
26. Cysteine (S^{35})	
Univ. of Calif. Citrus Experiment Station	P‡
27. Cystine (S^{35})	
Univ. of Calif. Citrus Experiment Station	P‡
Lankenau Hosp. Research Inst. (Temple Univ.)	P‡
28. Cytochrome C (Fe^{55})	
H. Beinert and H. Maier-Leibnitz (USAF School of Aviation Medicine, Randolph Air Force Base, Texas)	C(*42*)
29. Desoxyribo-nucleic acid (P^{32})	
Univ. of Minnesota	P‡
30. Digitoxin (C^{14})	
Univ. of Chicago	C(*18,19,20*)
31. Ergothioneine (C^{14})	
Cornell Univ. Med. School	P‡
32. Fats (I^{131})	
Mary Imogene Bassett Hosp.	P‡
Fats (C^{14})	
Univ. of So. Calif.	P‡
33. Fatty acids (C^{14})	
Univ. of Chicago	P‡
Univ. of Oregon	P‡
Univ. of Wisconsin	P‡
34. Formaldehyde (C^{14})	
Cornell Univ. Med. School	C(*52*)
35. Fumaric acid (C^{14})	
Oak Ridge Nat. Lab.	C(*57*)
36. Fructose (C^{14})	
Brookhaven Natl. Lab.	C(*4*)
Oak Ridge Nat. Lab.	C(★)
37. Glucose (C^{14})	
Univ. of California	P‡
Brookhaven Natl. Lab.	C(*4*)
C. A. Dubbs (U. S. Veterans Admin. Center, Los Angeles)	C(*10*)
Gen. Foods Corp.	P‡
Harvard Med. School	C(*15*)
Scripps Metabolic Clinic	C(★)
Univ. of So. Calif.	P‡
Tufts College	P‡
Oak Ridge Natl. Lab.	C(★)
38. Glutamic acid (C^{14})	
Univ. of California	C(*35*)
Univ. of Rochester	C(*37*)
39. Glutathione (C^{14})	
Harvard Med. School	P‡
Univ. of Chicago	C(*29*)
Glutathione (S^{35})	
Reed College	P‡
40. Glycerol (C^{14})	
Univ. of Illinois	P

41. **Glycine** (C^{14})
- Univ. of California — C(*30*)
- Univ. of Illinois — P‡
- Natl. Inst. of Health — P‡

42. **Glycogen** (C^{14})
- Howard Med. School — C(*27*)
- Univ. of Indiana — P‡
- Tufts College — P‡

43. **Glycosides** (C^{14})
- Univ. of Chicago — P‡

44. **Heptanoic acid** (C^{14})
- Univ. of California — C(*58*)

45. **Hemoglobin** ($Fe^{55,59}$)
- Chicago Med. School — P‡

Hemoglobin (C^{14})
- Univ. of Rochester — C(*40*)
- Washington Univ. — C(*39*)

46. **Hexose esters** (C^{14})
- Tufts College — P‡

47. **Hexosamines** (C^{14})
- Indiana Univ. — P‡

48. **Hormones** (S^{35})
- Sloan-Kettering Inst. — P‡

49. **Inositol** (C^{14})
- Oak Ridge Natl. Lab. — U(★)

50. **Isocitric acid** (C^{14})
- Calif. Inst. of Tech. — P‡
- Univ. of Chicago — C(*22*)

51. **Methionine** (S^{35})
- Univ. of Calif. Citrus Experiment Station — P‡
- Lankenau Hosp. Research Inst. (Temple Univ.) — P‡

52. **Morphine** (C^{14})
- Univ. of Louisville — C(★)

53. **Nucleic acids** (P^{32})
- Univ. of Rochester — C(*45*)
- Overly Biochemical Research Foundation — P‡

Nucleic acids (C^{14})
- New York Univ. — P‡
- Sloan-Kettering Inst. — P‡

54. **Nucleoproteins** (P^{32})
- Univ. of Chicago — P‡
- Univ. of So. Calif. — P‡
- Wadsworth Gen. Hosp. — P‡

55. **Organic acids** (C^{14})
- Calif. Inst. of Tech. — P‡
- Cornell Univ. — P‡

56. **Organic compounds** (C^{14})
- Harvard Univ. — P‡

57. **Organic phosphates** (P^{32})
- Duke Univ. — P‡

58. **Oxalacetic acid** (C^{14})
- Univ. of Chicago — C(*22*)

59. **Penicillin** (C^{14})
- Penn. State College — P‡

Penicillin (S^{35})
- Penn. State College — P‡
- Public Health Service — P‡

Penicillin (P^{32})
- Wadsworth Gen. Hosp. — P‡

60. **Phage** (P^{32})
- Washington Univ. — P‡

61. **Phosphogluconate, beta** (C^{14})
- Tufts College — P‡

62. **Phosphoglyceric acid** (C^{14})
- Oak Ridge Natl. Lab. — C(★)

63. **Phospholipids** (C^{14})
- Bowman-Gray School of Medicine — P‡
- Univ. of Chicago — P‡
- Lankenau Hosp. Research Inst. (Temple Univ.) — P‡

Phospholipids (P^{32})
- Univ. of Southern Calif. — P‡
- Rutgers Univ. — P‡
- Univ. of Southern Calif. — P‡
- Univ. of Tenn. Med. School — P‡

64. **Porphyrins** (C^{14})
- Columbia Univ. — U(★)

65. **Propanol** (C^{14})
- Univ. of California — C(*58*)

66. **Proteins** (I^{131})
- Mary Imogene Bassett Hosp. — P‡
- Peter Bent Brigham Hosp. — P‡
- Purdue Univ. — P‡

Proteins (C^{14})
- Calif. Inst. of Tech. — C(*28*)
- Univ. of Chicago — P‡
- Howard Univ. — C(*60*)
- Natl. Inst. of Health — P‡

Proteins (S^{35})
- Tufts College — P‡
- Reed College — P‡

67. **Purines** (C^{14})
- Amherst College — P‡
- Univ. of Chicago — P‡
- Cornell Univ. Med. School — P‡
- Natl. Inst. of Health — P‡
- Univ. of Penn. — P‡
- Sloan-Kettering Inst. — P‡

68. **Pyrimidines** (C^{14})
- Amherst College — P‡
- Univ. of Chicago — P‡
- Univ. of Penn. — P‡

69. **Pyruvic acid** (C^{14})
- Iowa State College — P‡

70. **Raffinose** (C^{14})
- Oak Ridge Natl. Lab. — C(★)

71. **Ribonucleic acid** (P^{32})
- Univ. of Minnesota — P‡

72. **Rubber** (C^{14})
- Calif. Inst. of Tech. — P‡

73. **Serine** (C^{14})
- Univ. of California — C(*30,31,33*)
- Columbia Univ. — U(★)
- Univ. of Illinois — P‡

74. **Silk** (C^{14})
- Mass. Gen. Hospital — C(*53*)

(*Continued on next page*)

LABELED COMPOUNDS PREPARED BIOSYNTHETICALLY—(Continued)

Compound; Isotope; Institution	*Status*
75. Starch (C^{14})	
Brookhaven Nat. Lab.	C(*3*)
General Foods Corp.	P‡
76. Succinic acid (C^{14})	
Western Reserve Univ.	P‡
77. Sucrose (C^{14})	
Brookhaven Natl Lab.	C(*6*)
Exp. Station of Hawaiian Sugar Planters Assoc.	P‡
Univ. of California	C(*54*)
Oak Ridge Natl. Lab.	C(★)
78. Sugars (C^{14})	
Cornell Univ.	P‡
79. Sulfonic acids (S^{35})	
Univ. of Calif. Citrus Experiment Station	P‡
80. Tobacco mosaic virus (P^{32})	
Stanford Univ.	P‡
81. Uric acid (C^{14})	
Univ. of California	C(*44*)
82. Valeric acid (C^{14})	
Univ. of California	C(*58*)
83. Virus (C^{14})	
Harvard Univ.	P‡
Virus (P^{32})	
U. S. Naval Med. Research Unit, Univ. of Calif.	P‡
Wadsworth Gen. Hosp.	P‡
Washington Univ.	P‡

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Practical Aspects of Surface Decontamination*

Results of extensive decontamination tests of materials, surfaces and coatings are reported here. Decontamination theory is considered, and step-by-step procedures for laboratory decontamination are given. Possible use of less expensive materials and reagents such as detergents is discussed

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SURFACE DECONTAMINATION has become more significant with the wide-scale use of radioisotopes. Many materials which are commonly used in radiochemical laboratories have proved difficult, if not practically impossible, to clean once they have been contaminated with a radioactive element.

For example, if an inactive solution of trisodium phosphate is spilled on a laboratory bench and then wiped up, the surface is considered clean. But if the phosphorus atoms in this solution of trisodium phosphate are radioactive phosphorus atoms, a more complete degree of cleaning may be necessary. At equivalent chemical concentrations, the number of phosphorus atoms that become tenaciously attached to the surface will, of course, be the same for both the radioactive and the non-radioactive solutions, since the chemistry of both solutions is the same. However, the radioactive atoms are objectionable for two reasons: 1. They constitute a potential radiation hazard to personnel working in the laboratory. 2. Because of cross contamination, they jeopardize the validity of experimental data (counting samples, etc.). For these reasons, it is necessary that routine inspections be made of the areas subject to contamination and affected areas cleaned to a permissible level of contamination (*1*).

In addition to the well-established criteria for evaluating a protective coating—corrosion resistance, abrasion resistance, ease of application, cost, etc.—there are two other criteria necessary for evaluating a surface material for use in a radioisotope laboratory. These two criteria are the susceptibility of the surface to contamination, and the ease with which it can be decontaminated to a permissible radiation level.

There is very little history on the use of various types of protective coatings in radioisotope laboratories. Therefore, empirical tests have been devised for the purpose of predicting their ease of decontamination and for comparing various materials. Since glass, polished stainless steel, unpolished stainless steel‡ and lead have been widely used in Atomic Energy Commission labora-

* Based on work done at Oak Ridge National Laboratory for the Atomic Energy Commission, first reported in Oak Ridge National Laboratory reports ORNL-381 and ORNL-382.

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‡ Polished stainless steel type 347 and unpolished stainless steel type 316 were used for these experiments.

tories, they are employed here as standards for comparison. The cost of these relatively expensive metals and glass for working surfaces in small radioisotope laboratories is often prohibitive. Cheaper protective coatings may be found that are capable of efficient use in laboratories working with activities of 100 millicuries or less in the total sample.

Past experience has shown that surfaces which can be used most efficiently in isotopes laboratories have the following general properties:

1. Smooth and nonporous (minimum of adsorption area and penetration)
2. Nonionic (minimum exchange)
3. Resistant to corrosion by acids, alkalis, organic solvents
4. Resistant to heat

Other pertinent points have been suggested in more extensive discussions of the subject (*2, 3, 4, 5*).

EXPERIMENTS

Since protective coatings are used on both porous and corrodible items, the best surface would be built up as follows:

First Layer—Seal Coat. This coat must penetrate the porous material to some depth (several mm on concrete or wood) and fill all the pores with a homogeneous, chemically resistant body.

Second Layer—Permanent Surface Coat. This is preferably a homogeneous extension of the seal coat. It should be resistant to those conditions to which it is destined to be exposed, and should have a low susceptibility for the radioelements of interest.

Third Layer—Final Surface Coat. This may be varied to suit conditions. In addition to the requisite chemical and physical properties, it should have a low susceptibility to contamination, and be easy to clean. In the case of flooring material, an exterior wax finish is often used.

The coatings tested consisted of several commercially available resins (paints and strip coats), plastics, and flooring materials.* These were applied to test plaques as nearly as possible in the manner and to the type of material recommended by the manufacturer. They were aged in a dust-free atmosphere with adequate ventilation for the prescribed time or longer. Those which required heat treatment were baked under the conditions prescribed by the manufacturer.

The finished plaques were stored individually and examined carefully before use. Since relatively minor defects such as scratches result in a rather large variation in both the susceptibility of the surface to contamination and its subsequent ease of decontamination, only those plaques which presented a smooth, nonporous appearance were selected in an effort to obtain data under the best possible conditions.

The radioisotopes used to contaminate the plaques were carrier-free† $H_3P^{32}O_4$ in hydrochloric acid solutions (*p*H 2–3), $Ba^{140}Cl_2$ in hydrochloric acid solution (*p*H 2–3), and NaI^{131} in sodium bisulfite solution (*p*H 8). These particular isotopes were chosen because of their favorable radiation characteristics for this type of experiment. This combination also permits differences between anions and cations to be studied.

Susceptibility Tests

The susceptibility of a surface toward contamination by a particular ion is indicated by the sorption of that ion from an aqueous medium. In the susceptibility test, illustrated in Fig. 1, 0.1 ml of the contaminant was pipetted onto the surface near the end of the 1.25 × 2.5 inch test plaque. The en-

* The inclusion or exclusion of specific materials in these tests does not constitute an endorsement or rejection of any product.

† No isotopic carrier added deliberately during the production. The total solids were of the general order of 0.04 mg/ml.

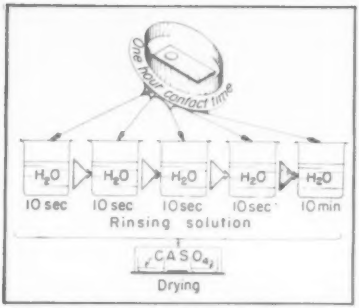

FIG. 1. Test used to determine susceptibility of various surface materials to radiocontamination

tire plaque was covered by an inverted watch glass to minimize evaporation of the radioactive solution. It was allowed to stand for one hour, after which the solution was carefully drawn off with a transfer pipette. The plaque was washed immediately using a standardized method, dried over calcium sulfate, and monitored. The remaining radioactivity was a measure of the susceptibility of the surface to contamination. (For the purpose of these experiments, water, by itself, is not considered to be a decontamination reagent.)

The susceptibility test does not distinguish the method by which the attachment occurs. The radioelement, in the general case, may be held by chemisorption (e.g., ion exchange) with surface valences, by physical adsorption, or by mechanical means such as diffusion into cracks and pores on the surface. The form in which the radioelement occurs on the surface depends largely on the chemical composition of the medium from which it is deposited.

With the susceptibility test, it is fairly easy to distinguish between porous and nonporous surface materials. The porous materials will absorb 1% or more of the radioisotope from the solution during the one-hour contact period, whereas the nonporous materials will retain much less than 1%. As a matter of fact, nonporous materials often retain less than 0.01% except when specific chemical reactions occur between the surface material and the radioelement in the solution.

Decontamination Tests

The square plaques were contaminated by pipetting 0.1 ml of the active solution onto the center of the surface area, as illustrated in Fig. 2. A funnel, one inch in diameter, was mounted in such a position that it could be lowered over the drop of solution to within a few millimeters of the plaque. A vacuum was applied through a filter to the stem of the funnel. The air flow through the funnel was adjusted to a velocity which prevented the solution from flowing near the rim of the funnel. By this means, it was possible to evaporate the solution to dryness in approximately one hour at room temperature. Activity was confined to the center of the plaque.

A stepwise decontamination procedure similar to that used in radioisotope laboratories was used for this work. Reagent decontamination without scrubbing (Step 1) was used first to lower the activity level as much as possible before personnel exposure became necessary. Then 0.25 ml of the decontamination reagent was applied to the affected area and allowed to stand for a period of three minutes before removal from the area with a transfer pipette.

After each decontamination step, the plaque was rinsed with a spray of water, blotted dry, and monitored. Each subsequent attempt at decontamination (Steps 2, 3, etc.) was accomplished by applying 2 ml of reagent and brushing manually with a surgical brush for one minute. Radioautographs demonstrated that the activity was rather uniformly deposited over the contaminated area, and that less than 1% of the remaining activity was spread to

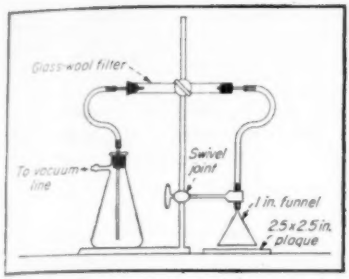

FIG. 2. **Drying unit used in preparing samples for the decontamination test**

other parts of the plaque during the brushing process.

The decontamination data are reported in terms of a newly defined quantity called the Decontamination Index (D.I.). This value is the common logarithm of the ratio of the activity on the surface before decontamination to the activity on the surface after decontamination.

The tests were run in duplicate, and the over-all precision obtained was ±0.3 Decontamination Index unit.

Several observations of interest are evident in the general pattern of the results. The most consistent feature is the fact that the cleaning action of any reagent is, for all practical purposes, completed at the end of the second step in the decontamination procedure. Also, the first whole number of the decontamination index is usually established at this time; further attempts to reduce the contaminant on the surface are relatively ineffective. Thus, it can be found almost at once if the decontamination index on any particular plaque is going to be 2, 3, or 4, etc.

There is no striking benefit achieved by adding to the cleaning reagent a carrier which is isotopic with the radiocontaminant. Those effects which were observed were far less than they should be if the radioisotope were exchanging significantly with the carrier.

These results, as well as some of the finer points, are qualitatively explainable by a simplified picture of the decontamination process. One would expect that the first action of a liquid reagent would be simply to dissolve any salts of the radioelement that might be lying loose on the surface. Another immediate action would be the rapid adsorption of solute ions originally present in the cleaning solution, and exchange between the surface and solution where such exchange is possible.

Part of the cleaning effect will depend on how fast these solvent ions can reach the surface, and on the degree to which they can react with the surface valences in competition with the ions of the radioelement. Thus, the effect of acids is primarily due to the hydrogen ion and secondarily due to the anion.

The radioelement will ultimately become distributed between the solution and the surface in the proportions determined by its distribution coefficient between the cleaning solvent and the material. However, the rate at which the equilibrium is attained might well follow an exponential law, since the various rate equations hold for both adsorption and desorption steps. If a diffusion process (e.g., diffusion from micropores) is involved in the decontamination, a slow rate of exchange could easily result, because a rapid replacement of solution would not occur at contamination sites deep in the pores.

Regardless of the explanation, if the exchange rate were slow enough, the radioelement would appear to be irreversibly attached to the surface. A slow exchange rate would also account for the repeated observation that isotopic carrier contributes far less to the displacement of the radioelement than one might expect from its concentration in the reagent.

Corrosion Tests

The purpose of the corrosion test is twofold: 1. To determine the resistance

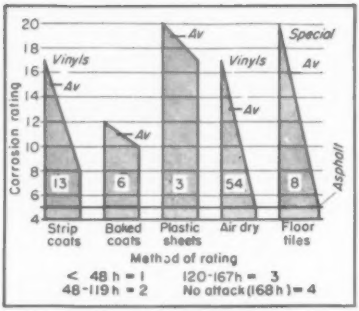

FIG. 3. Average corrosion rating for various groups of protective coatings exposed to three acids, a caustic, and an organic solvent. Figures in shaded columns denote number of coatings tested. Corrosion rating given is total for all types of tests

of selected laboratory materials to common laboratory solvents. 2. To explore the extent to which reagent decontamination procedures can be used for laboratory maintenance.

The various coatings were applied to rounded rods of soft wood or aluminum which were $\frac{3}{8}$ in. in diameter and 5 in. long. For materials other than coatings, immersion strips were cut from the parent material. Separate experiments with each reagent were made by immersing test rods at room temperature for a period of one week in 3*M* solutions of HNO_3, HCl, H_2SO_4, NaOH, and in hexone (methyl-isobutyl ketone, selected as a "typical" organic solvent).

Failure of each material was indicated if the reagent became badly discolored, the coating or material became soft or tacky, or "bleed through" was indicated by discoloration of the coating at a level 0.5 cm above the immersion level. The materials were rated in groups as indicated in Fig. 3. The average corrosion rating for each material was computed by adding the values achieved with each of the five reagents. Thus a rating of 20 indicates that the coating withstood all of the reagents for at least 168 hours. The figures within the shaded area denote the number of coatings tested within each classification. The peak of the column denotes the best material, the low point denotes the worst, and the average value for each group is indicated by the abbreviation "Av."

CALCULATIONS

The percentage of the radioisotope adsorbed (susceptibility) may be written as

$$\% \text{ adsorbed} = \frac{(\text{Activity adsorbed on surface}) \times 100}{(\text{Total activity of sample applied})} \quad (1)$$

The degree of decontamination that can be achieved is defined as decontamination index (D.I.)

$$\text{D. I.} = \text{Log} \frac{\text{Activity on surface before decontamination}}{\text{Activity on surface after decontamination}} \quad (2)$$

Spill Index

In evaluating the ease of decontaminating a spill, it is desirable not only to

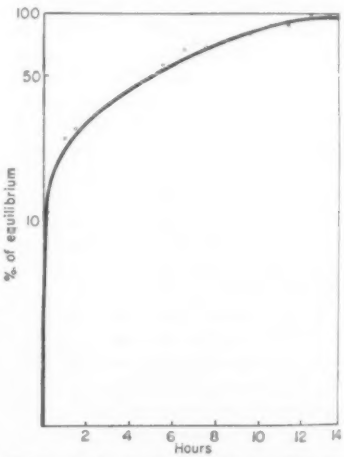

FIG 4. Rate of adsorption for radioactive phosphoric acid on glass

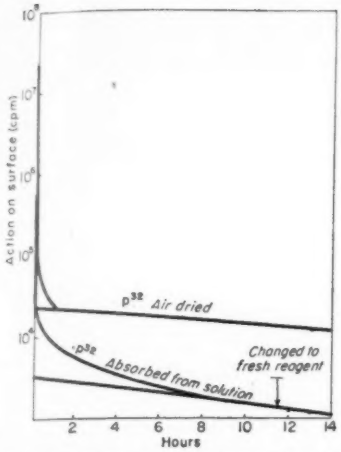

FIG. 5. **Desorption of P^{32} from glass by immersion in a 500-ml volume of 3*N* nitric + 3*N* phosphoric acid**

compare different materials; but also to get an estimate of how much activity will be left after the decontamination process. For the experimental conditions used, the most accurate procedure would be to remove the activity retained by the adsorption test, and obtain the ratio of activity left after a two-step decontamination procedure to the total activity applied in the initial contaminating solution. This method is technically impractical because it would require the use of very "hot" initial solutions to leave enough activity at the end of the experiment to get an accurate count. However, an estimate of this value can be made by dividing the fraction adsorbed by the amount of decontamination that can be achieved. Thus, from Eqs. 1 and 2

$$\text{Activity remaining} = \frac{\%\ \text{adsorbed}}{\text{D. I.}} \quad (3)$$

From the experiment illustrated in Fig. 5, and other tests, it has been estimated that the proper index would usually be one to two units less than that obtained by the above indirect method. Therefore, to a rough approximation, the D. I. achievable in practice is simply two units less than the value given by Eq. 3. The same numerical result is obtained if the fraction adsorbed is expressed as per cent adsorbed and the logarithm of this value computed. When Eq. 3 is written in the logarithmic form, it gives a value which is defined as the Spill Index.

Spill Index (S. I.)

$$= \text{Log}\ \%\ \text{adsorbed} - \text{D. I.} \quad (4)$$

This value will be negative; the minus sign is dropped, however, and the values are listed as positive numbers.

EXCHANGE MECHANISMS

A typical curve for the adsorption of $H_2P^{32}O_4$ on glass is shown in Fig. 4. In this experiment, the end of a frosted microscope slide* was immersed in a solution of radioactive phosphoric acid, removed at intervals, rinsed in successive changes of distilled water, and monitored.

It should be noted that a very rapid phase of adsorption deposited an amount equivalent to a few tenths to a few per cent of the ultimate equilibrium amount of P^{32} within a matter of seconds after the solution and surface were brought together. This is a typical feature of the adsorption of polar ions on different surfaces; it is attributed to electrostatic adsorption or ion exchange at the outer surface of the electric double layer at the solid-solution interface (*6*).

The two phases were represented by straight lines with half-times of 10 minutes and 9 hours. The 10-minute step was essentially complete after the first hour, the total activity at this time being about 25% of the equilibrium value. In the adsorption of polar ions, such steps commonly follow the rapid initial adsorption at the surface of the double layer and are usually attributed

* Frosted glass was used for this particular experiment so that less active P^{32} solutions could be used. The frosted glass provides a better adsorptive surface than smooth glass.

to successive steps, one of which is probably due to diffusion of the radioelement through the double layer (*6*, *7*).

The fact that the semilog plots were straight lines, of course, indicates an exponential equation for the lines. This is in accord with the observation of Boyd et al. (*8*), that an exponential equation is obtained when the reaction kinetics of the exchange occurring between a solution and an ion-exchange resin are calculated for either a diffusion-controlled or a chemical-exchange mechanism. An exponential equation is also obtained for the exchange between a radionuclide and its stable isotopes in the same ionic form, when the stable ion is initially in exchange equilibrium in two or more compartments and the radionuclide is introduced into one of them (*9*, *10*). Because of the widespread occurrence of stepwise exponential adsorption (*6*, *7*, *8*, *9*, *10*), it is logical to expect that adsorption quite generally will show rapid initial stages and subsequent slower stages, each stage being exponential in character. The form of the adsorption curve observed in this experiment proved to be the rule rather than the exception for the adsorption conditions used in these studies.

This experiment is the basis for selecting a one-hour contact time in the susceptibility test. A more exact comparison at a later time is not necessary, because the magnitude of the total adsorption can be determined by allowing the reaction to go through only this first phase.

Two experiments (illustrated in Fig. 5) were set up to determine the extent to which exchange rates might be important in the reagent decontamination process. In the first experiment, some of the slides which had been equilibrated with a P^{32} solution for the adsorption experiments were then cleaned by immersion in 500 ml of a $3N$ HNO_3 – $3N$ H_3PO_4 solution which was continuously agitated. In the second experiment, slides on which the P^{32} had been allowed to dry overnight over $CaSO_4$ were cleaned by the same procedure. The slides were removed at intervals, rinsed, dried and monitored.

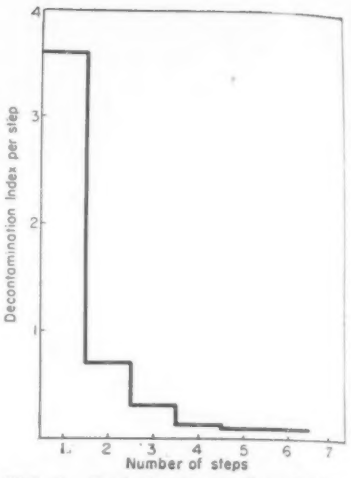

FIG. 6. Typical stepwise decontamination sequence illustrating removal of P^{32} from Pyrex glass No. 774 with a solution of $3N$ nitric + $3N$ phosphoric acid.

In the first experiment, about 98% of the adsorbed activity was removed during the first 10 minutes. The activity then came off with a half-time of about 70 minutes, followed by a third step with a half-time of around 9 hours. Practically all the desorption obtained during the 15-hour run was obtained during the first 6 hours, at which time the decontamination index was 2.4 as compared to only 2.7 at 15 hours. The fact that the 9-hour slope was not altered by changing to fresh reagent proves conclusively that the exchange rate was the limiting factor, and that the position of the ultimate equilibrium had little or no influence on the rate at which the P^{32} atoms were removed from the glass. If one needs to remove, in a short time, 99.9% of the activity

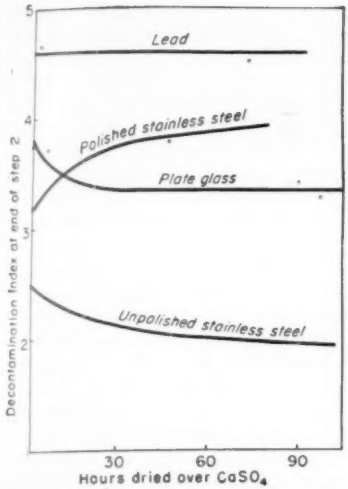

FIG. 7. **Effect of dehydration on the Decontamination Index of P^{32} applied to various surface materials**

remaining after 6 hours, it will be necessary to attack the surface itself.

The second experiment on air-dried material changes none of the essential conclusions of the preceding discussion. In this case, the decontamination index was 3.0 after 2 hours immersion, and only 3.2 after 15 hours. The difference between the fast and slow desorption steps was discernible in each case within the first few minutes of the experiment.

The same striking similarity is observed if a stepwise decontamination procedure is used. The results are shown in Fig. 6. The same materials and cleaning reagent were used.

The amount of radioactivity that can be removed from the surface comes off quite rapidly at first. Extended effort with the same cleaning reagent is somewhat ineffective. The stepwise procedure actually measures that fraction of the total contaminant which reacts with or diffuses into the surface prior to the cleaning operation and which cannot be readily removed. The size of this fraction can be determined by carrying the stepwise decontamination procedure through only two steps.

In order to achieve reproducible results on the decontamination tests, it was necessary to take all of the plaques to uniform dryness. Figure 7 shows the effect of dehydration on the decontamination of P^{32} from the selected surfaces. On the basis of these tests, it was found that reproducible results could be achieved with a drying time of 24 hours.

STANDARD REAGENTS

The procedures already discussed make it possible to compare the operation of any one variable if the other important variables can be controlled. The important variables are the surface material, the contaminating conditions, and the cleaning reagent.

Some standardization has already been achieved in the selection of the surfaces to be tested, the composition of the solutions used as the contaminating reagent, and the manner of its application. It is still necessary to select a "standard reagent" if either different surfaces or contaminating conditions are to be systematically surveyed.

A large number of complexing agents, chelating agents, synthetic detergents, organic solvents, mineral acids and alkalis were tested for their efficiency in removing P^{32}, Ba^{140}, and I^{131} from four selected surfaces. With each radioelement, it was found that at least one cleaning reagent appeared well up on the efficiency list for the removal of that element from these surfaces (*11*). Therefore, a "standard reagent" was selected for each element as follows:

For P^{32}: $3N$ $HNO_3 + 3N$ H_3PO_4
For Ba^{140}: $6N$ HNO_3
For I^{131}: 56% HI

Although one would hardly expect to use these particular reagents regularly for cleaning floors and tables, they do provide a standard against which milder

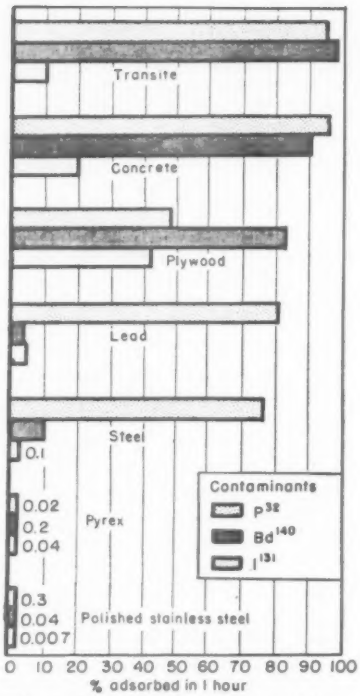

FIG. 8. Susceptibility of various laboratory surface materials to contamination

reagents can be compared as well as a standard through which other selected variables may be compared.

MATERIALS

The difficulty experienced in decontaminating many materials used in radiochemical laboratories has led to the general conclusion that radioactive decontamination and surface erosion are practically synonymous. Therefore, considerable emphasis has been placed on a search for materials which are resistant to chemical corrosion and abrasion, with much of the emphasis being placed on properties permitting replacement of sections which are highly contaminated.

Complete reliance on the use of expendable materials for permanent fixtures is less satisfactory in many instances than the use of more permanent surfaces which can be satisfactorily decontaminated by ordinary reagent techniques. Also, many persons in relatively small institutions do most of their work at activity levels low enough to permit proper maintenance by the cheaper decontamination procedures.

A systematic study of the radioactive decontamination properties of laboratory surfaces has revealed a number of interesting facts. Figure 8 illustrates the susceptibility of various laboratory structural materials to contamination. Due to their high porosity, the more widely used materials such as Transite, concrete, wood and structural steel show a high susceptibility to contamination. They are quite difficult to clean, and extended efforts at decontamination are considered to be of little value. Surface removal is the only effective means of cleaning the contaminated areas.

In all cases I^{131} was adsorbed in less quantity than P^{32} or Ba^{140}. However, it was found that the iodine which did become attached was more difficult to remove than the other radioelements.

As was expected, stainless steel and Pyrex glass, whose surfaces are smooth and nonporous, adsorbed a comparatively small amount of the radioisotopes. They are shown here for the purpose of illustrating the difference between the two types of materials. Lead, which is also comparatively nonporous, illustrates the effect of a specific chemical reaction between the surface material and the radioactive solution.

The average susceptibility of several types of protective coatings is illustrated in Fig. 9. The data are plotted on a logarithmic scale so that Transite and concrete may be included for comparison. A great many of the coatings tested are as good as, or better than, stainless steel or Pyrex glass; all of the

coatings represent a great improvement over Transite, concrete and plywood.

If a spill occurs, and the radioactive solution is removed from the surface at once, only a portion of the radioactive atoms will remain adsorbed on the surface as contamination. This is illustrated on the right-hand side of Fig. 10. The entire length of the vertical line represents the total amount of radioactivity that was spilled. If the spill is cleaned up immediately, a large part of the radioactivity never becomes attached to the surface; this quantity is listed as "Not Ads." Much of the contamination which is adsorbed can be removed by subsequent reagent decontamination; this quantity is listed as D. I. (Decontamination Index). Therefore, the Spill Index evaluates a surface with respect to two criteria, (a) susceptibility to contamination (per cent adsorbed in one hour), and (b) ease of decontamination. It was shown in Eq. 3 that a single value can be obtained which will combine the susceptibility and subsequent ease of decontamination. This is designed to estimate the fraction of the total radioactive sample that is likely to remain tenaciously attached to the surface if a spill occurs and is decontaminated within an hour. However, this does not make a distinction as to whether an apparently good material is useful because the adsorption is low, or because a very large fraction may be removed by reagent decontamination even after the surface has dried, or both.

Figure 10 also shows the average Spill Index for several groups of materials investigated. Since the term "index" denotes a common logarithm, a spill index of 8 indicates that all but 1 in 10^8 parts of the total contamination were removed. The explanation given for the various columns in Fig. 3 applies to this figure.

With the strippable paints, it was possible to achieve absolute decontamination if the radioactive solution had not bled through. If 10^8 cpm of radioactivity were applied, it was possible for the coating to receive a Spill Index of 8.

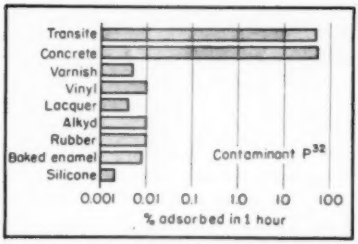

FIG. 9. Susceptibility of several types of protective coatings to contamination by P^{32}. Transite and concrete are included for comparison

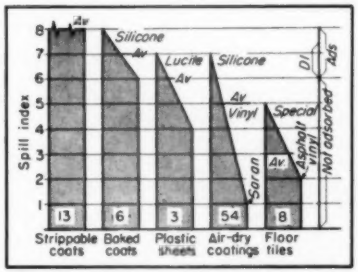

FIG. 10. Average spill index for various groups of laboratory surface materials. A graphic illustration of the spill index is also shown

The strippable paints would logically be used under circumstances where reagent decontamination is not practical; therefore, their chemical resistance and susceptibility to contamination are of primary importance. Unlike permanent surfaces, it is often desirable that these coatings hold all contaminants permanently so they will not rub off during the stripping process.

The figures are for the most part self-explanatory. Therefore, only a few points of general interest will be discussed specifically.

1. A better correlation on various types of materials could be made if a detailed knowledge of the chemical

composition (i.e., fillers, solvents, plasticizers, etc.) of each coating were known.

2. The combination of the contaminating conditions, the surface material and the decontamination reagent constitute a system of three interdependent variables which leads to a high degree of specificity in cleaning efficiency. Therefore, extrapolations to new situations are extremely uncertain, and it is difficult, if not impossible, to predict what will happen.

3. Since porosity and roughness were minimized in the selection of the materials, a so-called good surface could be correlated more directly with its water repellency than with any other one property. For example, the silicones as a group stand out because of their uniformly high spill index. Most of this comes from their uniformly low adsorption values.

4. The rather uniform pattern obtained with iodine is interpreted to mean that the I^{131} is adsorbed very slowly as compared to Ba^{140} and P^{32}. But once attached to the surface it becomes very difficult to remove. This behavior is consistent with the fact that most of these materials contain double bonds with which iodine can react irreversibly as it becomes oxidized by the air. Therefore, the use of plastics and paints with I^{131} can be expected to lead to some difficulties.

5. The results obtained on floor materials, which have been selected in the past because of their outstanding abrasion and chemical resistance, were uniformly poor. Reagent decontamination has little chance of success in their maintenance. However, other materials which have not yet been extensively used in radiochemical facilities show considerable promise since, on the basis of experimental results, they should compete favorably with some types of stainless steel, when judged only on their decontamination properties.

6. Several of the materials examined have been shown to be basically superior in decontaminating properties to glass, lead, or stainless steel when used with P^{32} and Ba^{140}. Many more are comparable.

7. It is concluded that a very wide range of plastics and resins can be used efficiently in laboratories using 1 mc or less activity in the total sample. A smaller number are basically capable of efficient use up to approximately 100 mc. The authors consider that efficient routine use depends on the ability to reduce a surface contaminant to a level near "tolerance" by reagent methods without resorting to surface erosion.

A smooth, homogeneous material from which the superficial (monomolecular) layers can be dissolved without significant penetration of the underlying surface by the solvent makes it possible to remove even the surface-bound contaminants efficiently by reagent methods. If the proper solvent could be found for generally unsuitable materials, their useful range could be improved markedly. Further developments along these lines should push the range of their efficient use into the low curie region.

USE OF DETERGENTS

A beginning has been made toward evaluating the efficiency of less corrosive reagents, such as detergents, which would be the ones used in practice. These would be expected to vary in efficiency from one material to another. Several detergents in each of the anionic, cationic and nonionic classification were tested and their efficiency at removing radiocontamination from several types of surfaces tabulated (*11*). All of these tests pointed up the fact that reagent decontamination involves the interaction of at least three major variables—the surface, the radioelement, and the decontamination reagent.

A protective colloid was tried in conjunction with an anionic detergent and

with a nonionic detergent on both Lucite and glass. The purpose of the protective colloid is to prevent redeposition of the contaminant. It caused a marked improvement in the action of the anionic product, but had no apparent effect on the nonionic product. This observation is consistent with the anticipated specificity of detergent action, which at present is based on the thought that the reaction of the detergent with the surface material contributes far more to its cleaning efficiency than does a reaction between the reagent and the radioelement. Additional evidence pointing in the same direction is the fact that a chelating reagent (sequestrene) was much better for removing P^{32}, with which there should be no chemical combination, than it was for removing Ba^{140}, with which it forms an insoluble complex, thus displacing the barium equilibrium toward the solution.

It was observed that on a particular material one or another of the elements could be removed more efficiently than the others. There was no consistent relation between the indices for the different radioelements when one used the same detergent for removing contamination from different surfaces. Chemical composition and physical properties are not always good clues to actual performance in use (*12*); therefore, performance tests are necessary before a particular detergent can be judicially evaluated. The development of detergents which have outstanding cleaning properties promises to be a matter of fitting the reagent to a specific job—at least until the mechanism of the action is better understood.

Despite the unfavorable comparison of many detergents with the standard reagent, the tests demonstrated that some may be found that are just as good as the standard reagent for removing a particular element from a particular surface material. Also, a large number of cleaning problems exist for which a decontamination index of 3 or 4 is quite adequate, and many of the detergents were basically capable of achieving this efficiency.

It should be noted, however, that the application of most detergents on flooring material such as asphalt tile was virtually useless. If these materials are selected for use in a radioisotope laboratory to take advantage of their proven wearing qualities, one should be prepared to adopt a maintenance policy of periodically replacing the contaminated areas.

STEPWISE DECONTAMINATION

Nonporous Surfaces

Since the decontaminability of a chemically resistant and nonporous surface with a particular reagent is controlled almost completely by that fraction of the activity that can be removed in a short time, a generally applicable system of decontamination may be devised by using a suitable reagent and a scrub brush. As illustrated in Figs. 5 and 6, effective equilibrium between the contaminated surface and the cleaning reagent is reached quite rapidly, and decontamination is increased very little by extended periods of scrubbing. Removing the contaminated reagent from the affected area and repeating the process with a clean brush and more of the uncontaminated reagent has proved to be a rapid and effective means of cleaning. Surface erosion should be avoided when possible, since this leaves the surface more susceptible to future contamination. Radioautographs have demonstrated that the amount of active material scattered to the unaffected areas in carefully executed decontamination operations is usually insignificant; even this may be effectively eliminated by masking off the surrounding areas.

Field Method. The following method is suggested for decontaminating non-

porous surfaces affected by the spill of a radioactive solution.

1. Tackle the job immediately. Promptness will usually be rewarded by an increase in the degree of decontamination achieved and a reduction in the effort required.

2. Confine the active solution to as small an area as possible. This may be accomplished with blotting paper or any other suitable material. This "first line of defense" should be included when assembling the equipment for any operation where a major spill is likely to occur.

3. Determine the extent of the radiation hazard. The degree of protection required is dependent upon the amount and nature of the activity involved. Protective clothing including rubber gloves and coveralls should be worn for all decontamination work, and rubber overshoes should be used if the material has been spilled on the floor. A respirator should be worn if atmospheric contamination is a possibility. The contaminated area should be monitored periodically during the cleaning process with a suitable survey instrument in order to determine the degree of decontamination being achieved and the radiation hazard remaining.

4. Draw off or remove any remaining radioactive solution. This may be accomplished with additional blotting paper or with an adaptation of the transfer pipette technique, and will substantially reduce the radiation and retard further contamination of the surface.

5. Keep the contaminated area moist. If the affected area is permitted to become completely dry, the difficulty of decontamination may be increased by a factor of 10 or more. Also, a contaminated area that is permitted to evaporate to dryness becomes a more intense source of radiation.

6. Leach the contaminated area batchwise two or three times with a suitable decontamination reagent. The reagent should be left in contact with the contaminated area for about three minutes and then withdrawn in the same manner as the original spill. This operation, in addition to the rapid removal of most of the original radioactive solution, will usually eliminate more than 99% of the contaminant.

7. Accomplish the remaining decontamination necessary with a scrub brush and a suitable reagent. Sufficient quantities of the reagent should be applied to the contaminated area to keep it moderately wet. Brushing may be accomplished with a scrub brush on a handle long enough to keep the operator beyond the range of permissible exposure. The affected area is scrubbed for a period of approximately one or two minutes, the reagent removed, the area rinsed, and the brush discarded. Efforts at decontamination should be continued stepwise with periodic monitoring until it is apparent that the particular reagent or procedure is contributing nothing further to removal.

Porous Surfaces

Porous surfaces are generally unsatisfactory for purposes of decontamination and should be protected with a chemically resistant nonporous coating. However, for cases where contamination of this type is unavoidable, the following procedure is outlined.

Concrete. The extent of decontamination and the ease with which it may be accomplished is dependent upon the surface finish. Surfaces which have been subjected to severe erosion are almost impossible to decontaminate. A smooth surface is more responsive, but the removal process usually renders the material more susceptible to recontamination and unresponsive to further decontamination.

Low-level contamination of smooth concrete may be decreased by scrubbing

(Continued on page 87)

Cavity Ionization Chamber for Measurement of Absorbed X-Radiation Energy

The cavity ionization chamber, as pointed out in this article, is not an accurate device for measuring local energy absorption from an X-ray beam over a wide range of energies. The author discusses theory and factors affecting accuracy

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THE CAVITY IONIZATION chamber has been widely used to circumvent the difficulties in determining dose in terms of the roentgen. It allows absolute measurement of energy absorbed locally from an X-ray beam. But many factors affect the accuracy of such measurements. These factors are considered in this article.

The roentgen is defined in terms of the ionization produced in *any* volume of air as a result (direct or indirect) of the secondaries produced through interaction of the original photon beam in a specific volume of air. At low energies (grenz rays) a roentgen evaluation is difficult to make because of the problem of sampling. Any measured ionization is likely not to be characteristic of the original beam because of the alteration of the spectral distribution of the beam within the measuring apparatus itself. At energies above a few Mev, roentgen evaluation is difficult to make because of the problem of ion collection. Those ions which may be regarded as progenies of the photons that enter the specific air volume (of the roentgen definition) are distributed throughout a much larger air volume and are not easily distinguishable from the progenies of other photons. Furthermore, even under the best conditions, the roentgen measures neither energy flux of the incident beam nor energy absorbed from the incident beam. The notion of roentgen "dose" is a misnomer.

As a consequence, the trend in dose evaluation is in the direction of measuring absolute energy absorbed. For this measurement of absorbed energy the cavity ionization chamber is attractive because of its sensitivity and convenience. Gray (*1*, *2*) has shown how the cavity ionization chamber is suited to the determination of absolute energy absorbed locally from a photon beam, and he has given the suggestion (*3*) of attainable accuracies of better than 5%.

Because of the prominent role which cavity ionization could conceivably play for dosage determinations in energy units, it may be of value to examine in some detail the characteristics of the cavity chamber for the measure of energy absorbed locally within an absorber from an incident X-ray beam. By "energy absorbed locally" is meant energy which is abstracted from the X-radiation beam and diverted to such a form that it is directly associated with the molecules within an arbitrary confine. The association may be of a temporary nature as, for example, in the case of excitation energy which is ultimately transformed

into light radiation, or thermal energy which moves off through diffusion or radiation processes.

The procedure followed here is:

1. An examination of the fundamental equation which relates the observed ionization to the energy absorbed.

2. A survey of the general conditions under which cavity ionization chambers are used.

3. Consideration of the accuracy to which evaluations can be made on the individual entities of the fundamental equation—those entities being relative specific local energy absorption, absorbed energy per ion pair, and ionization.

4. A brief review of comparative methods.

Fundamental Equation

The cavity-chamber method is based on Gray's fundamental relation for the energy absorbed locally per unit volume at a particular point within a solid medium:

$$\epsilon = JW\rho \qquad (1)$$

where J is the number of ion pairs per unit volume produced in a gas cavity containing the point; W is the average* energy locally absorbed from the secondary electrons per pair of ions formed in the cavity gas; and ρ is the relative value in the solid as compared to that in the gas of conversion from electron kinetic energy to locally absorbed energy per unit of true path length of the electrons.

Equation 1 is often referred to as the Bragg-Gray relation since Bragg (*4*) first employed cavity ionization in a related manner for a measure of the quantity ρ.

For a better description of the energy absorbed per unit volume at a particular point, ideally J in Eq. 1 should be replaced by J_0, where J_0 is the number of ion pairs per unit volume in the limit of zero volume about the point under observation:

$$\epsilon = J_0W\rho \qquad (2)$$

Actually, J_0 can at best be taken as the number of ion pairs per unit volume in the limit of some small volume V_0 about the point under observation. A restriction on the smallness of V_0 is set by the requirement that there be enough substance in the volume V_0 to exhibit the chemical properties of the macroscopic absorber. For practical measurements any convenient cavity volume may be employed in Eq. 1 if the volume selected is representative, that is, if it is sufficiently small that the value of J it yields is the same as the limiting value J_0.

Gray's development (*1*, *2*) of Eq. 1 is as follows: consider an arbitrarily shaped gas cavity a about a point P with each linear dimension of the cavity much less than the average range of the electrons in the cavity gas; and an imaginary volume b contained within the solid absorber. The volume b is shaped similarly to a, and each linear dimension of b is $1/\rho$ times the corresponding dimension of a.

Because of the selected geometry of the two volumes, degraded energy yields of ionizing secondaries of a given velocity traversing corresponding paths is the same in a and b. For one-to-one correspondence of secondaries in velocity and direction throughout both volumes, the ratio of the number of secondaries crossing analogous surface areas in a and b is ρ^2. Then, since the ratio of gas and solid volumes is ρ^3, the energy absorbed per unit volume in a is $1/\rho$ times the energy absorbed per unit volume in b. Thus, it is concluded that whenever there is JW energy absorption measured per unit volume of gas cavity at point P, we can say that there should have been $JW\rho$ energy absorbed per unit volume of solid at P if the solid material instead

* Average per ionizing secondary electron.

of the gas cavity had occupied the neighborhood of P and if there can be shown to be one-to-one correspondence of ionizing secondaries in velocity and direction in the two cases.

Gray does not prove the correspondence of secondaries (equivalence of flux) throughout the specially selected corresponding volumes. Instead, he proves only the unaltered distribution of electrons on the surface of an arbitrary enclosure within the solid if the solid material of the enclosure were to be replaced by gas. This seems hardly satisfying of the requirement for one-to-one volume correspondence of flux throughout a and b, particularly in view of the practical order of magnitude of the ratio of volumes a and b, which is 10^9 to 1.*

A basic difficulty of attempting to prove Eq. 1 conclusively lies in the paradoxical nature of the statement of the equation itself. Since for purposes of providing a measurement within a solid medium, a gas cavity replaces the solid medium in the vicinity of the very point which is under observation, Eq. 1 presumably evaluates the energy which would have been absorbed per unit volume of the solid at the point had there been no cavity around the point.

If one ignores the foregoing objections, which may be trivial in the last analysis, Eq. 1 is still subject to certain modifications before it fulfills in the general situation the objective of yielding a measure of energy absorbed locally. To take the item of energy dependence into account, we let $n(x,y,z,\theta,\phi,E)\ d\Omega\, dE$ represent the number of secondary electrons which pass through unit area at point (x, y, z) in the cavity per unit time having energies between E and $E + dE$, and which in direction are included within solid angle $d\Omega$. Then if $U(E)$ represents the specific ionization of secondary electrons (number of ion-pairs formed per unit of true path length) in the gas of the cavity, $\int_E \int_\Omega nU d\Omega\, dE$ is the number of ion-pairs formed per unit volume per second at (x, y, z), that is, J. Now by an extension of Eq. 1 to allow a spread of energies in the radiation processes, we obtain the energy which would be absorbed per unit volume of solid absorber at (x, y, z) as

$$\epsilon' = \int_E \int_\Omega nU\rho W d\Omega\, dE \qquad (3)$$

where $\rho(E)$ and $W(E)$ are generalized, energy-dependent quantities which correspond respectively to the quantities ρ and W which were defined in connection with Eq. 1. $W(E)$ is here regarded not as an average over electron energies, but over all processes (ionization, excitation, dissociation, etc.) that may transpire with those electrons which have a particular initial energy E at (x, y, z). If we write for the total number of secondaries with energy between E and $E + dE$ crossing unit area in the cavity per second regardless of angle

$$N(x, y, z, E)dE = \left[\int_\Omega n d\Omega\right] dE$$

then Eq. 3 becomes

$$\epsilon' = \int_E NU\rho W dE \qquad (4)$$

Symbolically, in order to obtain an expression which resembles the form of Eq. 1, we can write Eq. 4 as

$$\epsilon = J\overline{W\rho} \qquad (5)$$

but there still remains the problem of evaluating the weighted energy average of $W\rho$:

$$\overline{W\rho} = \frac{\int_E NU\rho W dE}{J}$$

Or, if W can be regarded as essentially independent of energy, the problem reduces to one of evaluation of $\bar{\rho}$:

* For the case of equivalent atomic number of wall and cavity materials, ρ is approximately given by the ratio of the densities of the two materials. Taking the density of the walls as 1 and of the gas as 0.001 gives $\rho = 1{,}000$; hence: gas volume a/solid volume $b = 1{,}000^3 = 10^9$.

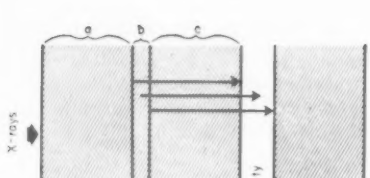

FIG. 1. Termination of secondary electrons within cavity

$$\bar{\rho} = \frac{\int_E NU\rho dE}{J}$$

Eqs. 3, 4, and 5 are identical with Eq. 1 if ρ and W are both independent of energy.

Formally, Eq. 4 admits of some further simplification. Recall that ρ equals local energy absorbed from electrons per unit path length in solid divided by local energy absorbed from electrons per unit path length in gas. Thus, $\rho \simeq S \equiv S_s/S_g$, where S_i is the collision component of stopping power in material i. (We shall later examine the accuracy of the approximation.) Now, since U is the number of ion-pairs formed per unit of true electron path length in gas

$$U(E)W(E) = S_g(E)$$

Thus,

$$U\rho\, W = \frac{S_s}{S_g} \times S_g = S_s$$

and Eq. 4 becomes simply

$$\epsilon' = \int_E NS_s dE \qquad (6)$$

General Considerations

In a practical ionization chamber of fixed cavity size, each linear dimension of the cavity must be less than the average range in the cavity of the ionizing particles which are created in the walls. This is desirable in order to emphasize the portion of the observed ionization which is caused by secondaries originating in the wall material, in preference to the ionization which is caused by secondaries originating in the gas. The observed ionization is then primarily representative of the walls.

The general situation is illustrated in the idealized scheme of Fig. 1 where 1. a plane wave incident X-ray beam is assumed advancing from left to right; 2. only those secondary electrons of initial energy E are considered; 3. scattering is not represented; and 4. the sections labelled a, b, and c are selected in the following manner: a is the region from which no electron (of initial energy E) reaches the cavity; b is the region from which many electrons terminate in the cavity and none cross the cavity; and c is the region from which most electrons penetrate the cavity. For a given incident X-ray beam and for a given thickness of absorber $(a + b + c)$ ahead of the cavity, the proportion of electrons of energy E which terminate in the cavity is a function of the amount and kind of gas in the cavity.

Similar arrangements and similar arguments apply for electrons of other energies. The desired effect of a minimal number of cavity-termination electrons thus entails minimizing the mass per unit area in the cavity by having either the cavity small, the gas pressure low, or both.

If there were no ionizing secondaries created in the cavity and if the secondaries from the walls penetrated into only a part of the cavity volume, there would result too low a value of the indicated ionization per unit volume as obtained from total ionization divided by total volume. It is interesting to note that, if this situation occurred, the measured ionization would not be appreciably altered by a decrease in pressure. Although the linear range of each electron in the gas would be extended, the density of ionizable gas molecules would be proportionally reduced. Thus, (aside from scattering

effects) until the pressure was sufficiently reduced to permit the electrons to completely cross the cavity, the indicated ionization per unit volume would be independent of pressure. Gray (5) contends that a considerable number of secondary electrons travel only very short distances from their points of origin so that, ideally, chamber cavity sizes are required which are of correspondingly short dimensions in order to avoid cavity termination of secondaries.

In the same light, since many secondaries travel only short distances from their origins in the solid, a fair proportion of those electrons which enter the cavity may have their origins within a thin layer of the chamber wall immediately adjacent to the cavity. Gray (5) directs attention to the steep front of the curve of ionization versus depth within an absorber (Fig. 2), which indicates that a major proportion of the measured cavity ionization is caused by secondaries arising close to the cavity surface. This suggests that one must use caution with a chamber having a wall of any given material coated by a thin conducting layer, because the thin conducting layer may possibly outweigh the rest of the chamber in the importance of its contribution to the total ionization.

For chambers with walls of a single material, for incident radiation of a limited energy range, and for sufficiently small cavity volumes, it is possible to provide a relative check on Eq. 1 by examining the experimentally obtained relation of ionization vs. gas pressure or of ionization vs. cavity volume. Linearity of such a relation would serve to confirm certain aspects of the expression $J = E/W\rho$ because ρ is inversely proportional to gas pressure and because E, W, and ρ are independent of cavity geometry. Sievert (6) has examined a representative group of cavity-chamber studies in this respect; a summary of

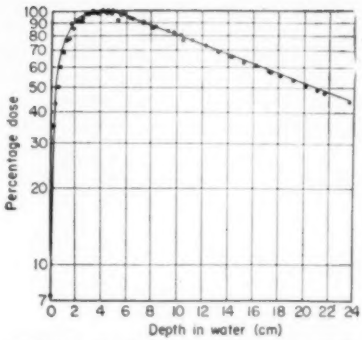

FIG. 2. Depth-dose distributions of 25-Mev X-rays J. S. Laughlin, W. D. Davis, *Science* **111**, 54 (1950)

these studies is given in Table 1. Many of the results listed indicate either linearity of ionization vs. volume or linearity of ionization vs. pressure. Wherever deviations from linearity occur, the deviations are all in the direction of excess ionization with reduced volumes or pressures.

It is possible that stray ionization through, for example, insulation leakage, could have contributed to the excesses noted in Table 1. Such effects would be relatively most predominant for small volumes and at low pressures and thus would be consistent with the direction of the deviations.

A further contribution to the deviations from linearity noted by Sievert could have come from the origin of secondary electrons within the cavity gas. This contribution is least for thick walls, because then the error caused by electrons originating in the gas is somewhat compensated by electrons stopping in the gas. On the other hand, walls that are sufficiently thin that the compensatory effect essentially disappears are most likely to be encountered at the higher energies where many secondaries created in the cavity probably possess sufficiently high velocity within the cavity that they produce little ioni-

TABLE 1. Survey of Cavity Ionization Work

Author	*Radiation*	*Chamber*	*Chamber material*
H. Fricke, O. Glasser *Am. J. Roentgenol.* **13,** 453 (1925)	Roentgen-rays 100 kv 1 mm Al – 200 kv 0.52 mm Aq + 0.75 mm Cu + 1 mm Al	Cylindrical. 0.6–2 cm Rectangular. 3.0 × 3.0 × 0.5 cm	C and Al
H. T. Meyer *Strahlentherapie* **41,** 185 (1931)	Roentgen-rays Hv 0.51–4.86 mm Al	Plane electrodes Rays limited by lead diaphragm. Diam. 0.4–1.0 cm	C with Al_2O_3
H. T. Meyer *Strahlentherapie* **41,** 309 (1931)	Roentgen-rays Hv 0.04–1.78 mm Cu	Spherical. Outer electrode 1.5–1.9 cm	C with Al_2O_3
E. Albrecht *Strahlentherapie* **42,** 328 (1931)	γ-rays	Cylindrical. Diam. 2.5–5 cm	C bakelite
E. A. Owen, H. I. Jones *Brit. J. Radiology* **4,** 309 (1931)	Roentgen-rays 37–100 kv	Cubical. Ca 1–4 cm	Graphite 1.5 cm thickness
R. M. Sievert *Acta Radiol.*, Suppl. 14, 82 (1932)	γ-rays 50 mg Ra Distance 2 and 4 cm	Spherical cond. chamber. Inside diam. 0.65–1.0 cm	Elektron metal. 0.2 cm thickness Inner electrode 0.8 cm
E. Miehlnickel, R. Rajewsky *Strahlentherapie* **50,** 499 (1934)	Roentgen-rays 165 kv, 0.5 mm Cu + 1 mm Al	Spherical. Outer electr. diam. 1.8 cm	Graphite + celluloid & silicon
E. Miehlnickel *Ann. Physik* **20,** 737 (1934) *Strahlentherapie* **54,** 348 (1935)	Roentgen-rays 25 kv, no filter 145 kv 0.8 mm Cu	Plane electrodes. Diam. 1.5 cm	(97 % C, 3 % Si) + 35 % celluloid C and Al
F. Keller *Strahlentherapie* **52,** 403 (1935)	γ-rays 50 mg Ra, 0.5 mm Pt	Spherical. Inside diam. 0.6, 0.9, 1.2 cm	Brass, 0.05 cm thickness
W. Friedrich, R. Schultze *Strahlentherapie* **54,** 553 (1935)	γ-rays	Spherical. Inside diam. 1.3–11 cm Cylindrical of diff. diam. and length but const. volume and cyl. of const. diam. and diff. length.	S-Graphite (Siemens-Plania) 0.4 cm thickness "
L. H. Gray *Proc. Roy. Soc. (London)* **A156,** 578 (1936)	γ-rays* A few millicuries radon filtered with just suff. mat. to stop the fastest natural β-particles.	– – –	Graphite 0.4 cm thickness " Lead
E. Miehlnickel, H. Osterwisch *Z. Physik* **101,** 352 (1936)	γ-rays 0.72 mg Ra Distance 20 cm	Spherical. Inside diam. 0.4–2.0 cm Electr. diam. 0.1–0.5 cm	(97 % C, 3 % Si) + 35 % Celluloid. 0.04 mm thickness. Inner electrode of C
M. Domeich *Fortschr. Gebiete Röntgenstrahlen* **57,** 189 (1938)	Roentgen-rays 165 kv max. 0.5 mm Cu + 1 mm Al Distance 50 cm	Spherical. Inside diam. 0.39–1.94 cm	97 % C, 3 % Si Inner electr. of C., diam. 0.11–0.51 cm

*Source described by Gray also used by Henschke.

Electrode distance cm	Air pressure cm Hg	Air volume cm^3	Tot. irr. electrode area / air volume	Result
0.22–0.95	76	0.48–4.91	10–3.4	Ionization prop. to volume.
0.24	76	4.47	8.0	
0.86–1.86	76	0.11–1.52	2.3–1	Small deviations (5–8 %) from proportionality with volume, probably due to secondary electrons from the electrodes and metal parts.
0.36–0.38	76	1.69–2.79	5.7–5.5	With different ratio total irradiated electrode area/air volume, the chamber wall must be made of carbon with different content of Al_2O_3, if the chambers shall be independent of quality.
1.8–2.3	76	31–90	1.9–1.2	Ionization prop. to volume if wall thickness sufficient ($\geq$ 4 mm graphite).
0.5–2	76	0.9–63.6	6–1	Ionization prop. to volume.
0.025–0.20	76	0.031–0.411	80–10	Ionization 5 % higher with smallest chamber.
0.85–0.26	76	3.21–1.93	7.9–3.2	Ionization prop. to volume except for the smallest electrode distances (0.3 cm) where the ionization per cm^3 was 7 % too large.
0.1–3	76	0.05–1.5	20–0.67	With celluloid-carbon-silicon electrodes ionization proportional to volume for soft rays. Deviations from proportionality increasing with hardness up to 200 % for the smallest electrode distance. Henschke and Gray have pointed out some errors in these experiments.
0.2–0.5	76	0.1–0.9	20–4	Ionization prop. to volume.
	76	1–675	4–0.5	Ionization prop. to volume and independent of type of chamber.
	76	–	–	
–	20–74	0.1	–	Ionization prop. to pressure.
–	10–74	2.0	–	"
–	20–74	0.1	–	Ionization per cm Hg increasing with decreasing pressure. Max. diff. 7 %.
0.15–0.75	76	0.03–3.7	17–3.5	Ionization per cm^3 decreasing down to 1.5 cm^3 volume, then increasing from 4 to about 6 at 0.03 cm^3.
0.14–0.71	76	0.031–3.75	17–3.4	Ionization per cm^3 increases with decreasing volume for smallest chambers (1–0.031 cm^3 volume) from 100 to abput 270.

† All these experiments showed a slight increase of the ionization with decreasing volume, although within the experimental errors.

Continued on next page

TABLE 1. (Continued)

Author	*Radiation*	*Chamber*	*Chamber material*
H. Henschke *Strahlentherapie* **62,** 614 (1938)	Roentgen-rays 50–145 kv 0.05–0.82 mm Cu	Spherical. Inside diam. 0.4 – 1.2 cm	(97 % C, 3 % Si) + 35 % Celluloid. 1 mm thickness
"	50–165 kv 0.05–1.00 mm Cu Distance 27 cm	Spherical Inside diam. 2.0 cm Electrode 0.3 cm diam.	"
"	50–145 kv 0.05–0.82 mm Cu	Cylindrical Length 3.8 Inside diam. 2.1 cm Inner electr. of diff. diam.	Graphite covered with air mat. 0.2 cm thickness
"	γ-rays* Distance 2.5 m	Plane electrodes	Disc of air mat. 1.5 cm diam. 0.8 cm diam. of radiat. cone

zation therein anyhow, and the need for their compensation is lessened.

In any event, if Eq. 1 is correct for the prescribed conditions, then, for any given wall thickness, linearity of ionization vs. pressure should serve as a criterion of the suitability of a particular volume cavity. This is because linearity with pressure can occur only under two circumstances—one is complete compensation of the effects of secondaries beginning and ending in the cavity, and the other is complete absence of both effects. With a small enough cavity it should be possible to approach the latter condition, except at very low energies where the required cavity may be impractically small.

Sievert, however, concludes that there is probably reality in the observed deviations from linearity which are reported by various workers in his review. Accordingly, he challenges the validity of Eq. 1 and proposes the possibility of a hitherto unobserved phenomenon of increased ion density near a surface, an effect which manifests itself when electrode spacings are made very small. Since the ratio of cavity surface area to volume goes up as the cavity volume is made smaller, any surface effect would be enhanced for small volumes.

The quantity S, which is defined by the relation $S = S_a/S_g$ which was introduced in connection with Eq. 6, is the relative collision-component stopping power. It represents the nearest approach to ρ in a conveniently measured physical quantity.

Before examining the differences between ρ and S, it is interesting to note that S, relative stopping power, is ordinarily computed as the ratio of individually measured absolute stopping powers of the two materials involved. The basic procedure is to measure for each material the loss of energy ΔE on the passage through a thickness of absorber Δx. In principle it would appear to be desirable for improved accuracy of ionization chamber work to attempt to measure one relative stopping power in place of two absolute stopping powers, and in this way to dispense with concern for those variable factors which would equally affect both parts in a combined set-up, but to date no experimental work of this type has been reported for electrons.

Stopping power as it is experimentally measured involves energy losses by any process whatsoever, including, particularly at higher energies, losses by radiation—Bremsstrahlung. And it is not simple experimentally to separate the losses so as to determine what fraction is caused by processes which contribute to *locally* absorbed

Electrode distance cm	Air pressure cm Hg	Air volume cm^3	Tot. irr. electrode area / air volume	Result
0.15–0.55	76	0.03–0.9	20–5	Ionization prop. to volume †
0.85	0.3–75	4.2	3.0	Ionization per cm Hg increasing with decreasing pressure below 10 cm Hg. With 0.3 cm Hg — 28 % higher ionization than at 75 cm Hg.
0.07–0.56	76	2.45–11.8	25–3.7	Ionization prop. to volume. †
0.1–1.0	76	0.177–1.77	5.7–0.57	Ionization prop. to volume. †

energy. The problem is further involved in that some of the ions formed in the neighborhood of a point under observation may be the result of collisions by electrons, which in turn arose through Compton or pair processes from the Bremsstrahlung. This complicates evaluating ρ at very high energies.

Incidentally, a number of workers (*7-11*), in a series of independent cloud-chamber studies with fast (2 to 11 Mev) electrons, have reported certain unaccountable energy losses believed possibly to be of a radiation nature but of a magnitude in excess—principally in heavy elements—of that predicted by the Bethe-Heitler theory for Bremsstrahlung (*12*). In these studies, observations of pairs was reported by only one laboratory (Skobeltzyn and Stepanowa). This group reported in addition several instances of absorption of the primary electron accompanied by the emission of a single positron.

In order to determine whether the excess losses could be attributed to neutrinos or to other penetrating radiation, Buechner and Van de Graaf (*13*) directed a 2-Mev electron beam onto a target immersed in mercury, the whole assembly constituting a calorimeter. The energy retained by the calorimeter equalled to within experimental error (less than 1%) the energy introduced into the system by the electron beam.

Reviews of early techniques for the measurement of the stopping power of electrons of energies between a few thousand and a few million volts are presented by Lenard and Becker (*14*) and by Bothe (*15*). Two extreme cases are considered, the "parallel" case for thin absorbers and the "normal" case for thick absorbers. In the parallel case, scattering is negligible, and the entrance and exit rays are approximately parallel. In the normal case, scattering is so extensive as to yield complete diffusion of electrons; additional absorber thickness serves only to decrease the number of electrons emerging from the absorber without appreciably altering relative emergent angular distribution.

In the parallel case, whereas there is no problem of diffusion, the energy loss ΔE is apt to be small by comparison with the energy E. Hence, the likelihood of an error in $\Delta E/\Delta x$ is great. Lenard and Becker indicate that a 1% error in deviation of slowed electrons from an original (unretarded) beam position in a magnetic field can easily introduce a 100% error in the derived stopping power.

In the normal case, following Lenard (*16*), experimenters distinguish between absorber thickness Δx and true track length of an electron Δl. The velocity

gradient $\Delta v/\Delta x$ is taken as the most probable velocity loss per unit thickness x in the same direction of entrance and emergence. The true velocity loss $\Delta v/\Delta l$ is then computed through a conversion factor. This conversion factor for the experimental work that is cited in the previously mentioned reviews, appears to be at best a crude estimate.

Slawsky and Crane (*17*) have made cloud-chamber studies of electron scattering in foils in which they apply the formula of Bethe, Rose, and Smith (*18*) to correlate foil thickness and true path length. For 0.9-Mev electrons incident on aluminum foils of 0.0025 and 0.01 cm thickness, there was sufficiently little scattering to permit application of the Bethe-Rose-Smith formula, but the associated losses were so slight that they could not be measured by magnetic deflection. On the other hand, with a 0.025-cm foil the loss was measurable, but the scattering was excessive. The true length computed from the formula was questionable. For 0.9- to 7.0-Mev electrons incident on lead foils of from 0.0038 to 0.05 cm thickness, Slawsky and Crane found scattering in every instance to approach diffusion. They concluded that under these particular circumstances no accurate evaluation of true length was possible.

Working with foils of the order of 500 A. U. thickness, Möllenstedt (*19*) has measured losses by a new high-dispersion method with which a loss of 0.1 ev is detectable in 35-kv electrons. The scheme employs the dependence of the chromatic abberation of an electrostatic lens on the velocity difference in off-axis electrons. Möllenstedt was interested in measuring atomic energy levels and, hence, he observed only discrete losses through thin foils in the forward direction. But the technique, with modifications, appears to be adaptable to the measure of general losses through any penetrable thickness of foil, with a limitation on upper energy set by

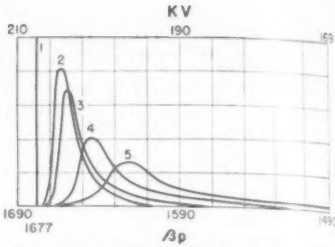

FIG. 3. Energy spreads found by Whitand Millington in originally mono-energetic electron beam on passage through thin foils

insulation problems of the electrostatic lens system.

Birkhoff, Hays, and Goudsmit (*20*) have recently reported investigations on most probable energy losses in million-volt electrons using a longitudinal magnetic field to confine the electrons to helical paths. Foils were placed at 180 degrees to the source and observations were made, photographically and with counters, of the displacement of the focus at 360 degrees. Be, Al, Ag, and Ta foils were employed, all of about 10 mg/cm² thickness. The authors indicated "reasonable" agreement with the theory of Landau (*21*).

The item of straggling is of some concern in electron-stopping measurement. An electron beam which is homogeneous on entering an absorber emerges with a spread of velocities, and the value of the most probable emergent velocity is a function of the experimental arrangement. The most probable velocity is different in electric and in magnetic analysis, and it is characterized by the particular properties of the detector employed. The detector may possibly be a photographic emulsion, a fluorescent screen, a scintillating crystal, a Faraday cage, a Geiger counter or an ionization chamber. Because of the nature of the distributions involved, any experimentally determined value of stopping power should be used with discretion or appropriately adjusted

before it is applied in Eq. 1 or in any similar relation.

In Fig. 3 are reproduced the well-known energy-spread curves obtained by White and Millington (*22*) with thin mica foils using magnetic analysis and photographic detection.

Bohr (*23*) and Williams (*24*, *25*) have shown that the most probable energy loss in thin foils is very much less than the average energy loss because of a small number of close collisions. These do not contribute much to the shape of the energy distribution curve near the maximum value, but do definitely affect the average energy value. An upper limit for the value of the collision energy loss which affects the most probable energy loss is given by Williams as $17.6\ NZe^4/mv^2$ where t is foil thickness.

From this expression it follows that about 1,500 volts is the maximum energy loss which contributed to the most probable value of the stopping power as measured by White and Millington. Laurence (*26*) has shown that taking into account this maximum measured loss value of 1,500 volts, the theoretical stopping power expression of Bloch (*27*) agrees within a few per cent with White and Millington's result.

If the quantity ρ in Eq. 1 is to be derived from the ratios of individual stopping powers, however, then what is wanted for individual stopping power is neither a most probable value that is characteristic of a particular experiment nor a theoretical average which results from ignoring certain violent collisions. What is required, instead, is a value that is representative of those electron losses which can be considered to be associated with *local* energy absorption.

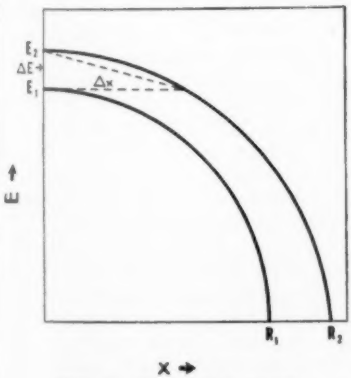

FIG. 4. Energy loss curves

Some recent work on stopping power for electrons is based on range-energy relations in nuclear photographic emulsions (*28*, *29*). Standard deviations in the range measurements reported by Zajac and Ross run as high as 28%. But even if precise representative figures for range could be obtained, this method—or any range method—yields doubtful values of differential stopping power.

If R_i is the range of an electron beam of initial energy E_i, then $(E_2 - E_1)/(R_2 - R_1)$ gives an approximate evaluation of stopping power. In order to examine the accuracy of such a relation, two hypothetical curves of E versus x for electrons have been constructed in Fig. 4. One curve is for electrons of initial energy E_1 and range R_1; the other is for electrons of initial value E_2 and range R_2.

The initial energies and the ranges establish the end points of the curves. The intermediate course of each curve is unknown, but simply for the argument it is assumed to be as shown in the illustration. If dE/dx is wanted for $E = E_2$, it can be read off the diagram as $\Delta E/\Delta x$ at the point $x = 0$ on the top curve, and the accuracy is as good as that of the approximation $dE/dx \simeq \Delta E/\Delta x$. Further, if it can be shown that $\Delta x = \Delta R$, it follows that $dE/dx \simeq \Delta E/\Delta R$. Then there is actually no need for a knowledge of the intermediate course of the curves. Ideally, from $E = E_1$ down to $E = 0$, the two curves are identical except for a lateral translation of position, and, hence, for any

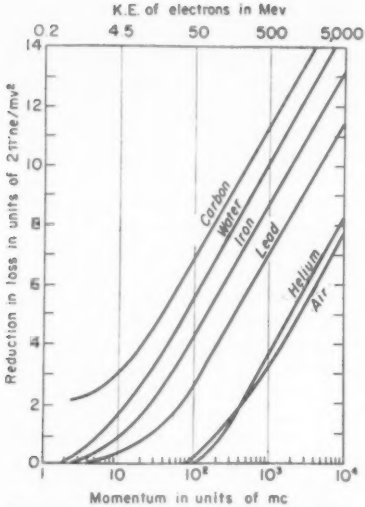

FIG. 5. Plot of differences between electron collision losses as computed by Bethe-Bloch and by Halpern-Hall

particular ordinate Δx is constant, thus equal to ΔR.

There is, however, the additional feature of straggling to consider. With the exception of the left end point, each ordinate on one of the curves of Fig. 4 represents a most probable energy value in a distribution. The curve of this distribution alters in shape with the depth of penetration, x, of the electron beam (see Fig. 3). As a result Δx may differ from ΔR, and a reasonable estimate of the magnitude of the difference requires a knowledge of the course of the energy spread with penetration. This may amount essentially to a requirement of experimental data on dE/dx, which is just what the range–energy technique is supposed to circumvent. The extent of the deviation of ΔR from Δx is least for small ΔE, i.e., for small ΔR too, but under this circumstance the possible error in the ratio of ΔE to ΔR could easily become excessive, because ΔE and ΔR are obtained as small differences between discrete values of the corresponding quantities: $\Delta E = E_1 - E_2$ and $\Delta R = R_2 - R_1$.

The cloud chamber is sometimes employed for the study of electron stopping in gases (*30*). Such an arrangement yields average stopping power as the ratio of total energy loss to mean range. One actually obtains from the data the quantity $\Delta E/\Delta \bar{R}$, which can be converted to yield $\Delta \bar{E}/\Delta R$ (the bars denoting averages) through a relation of Williams (*31*). The cloud-chamber method has the advantage of elimination of scattering error in the determination of true range of individual electrons, because complete track lengths are visible. However, this method yields average, and not differential, stopping power. Also, it is limited to electrons of initial energy below 100 kv whose ranges can be accommodated in chambers of practical size.

For ionization chambers which are filled with a gas mixture having the same effective atomic composition as the walls, the relative stopping power is frequently taken as simply equal to the ratio of the specific gravities of solid and gas. This presumes that atomic stopping power is independent of physical aggregation and of chemical binding. In a study of loss of energy of slow (0–200 volt) electrons in silver foils, however, Katz (*32*) claimed a marked effect related to the previous treatment of the foil. Furthermore, at high energies, Halpern and Hall (*33*) have theoretically treated the problem of ionization loss of electrons, taking into account the polarization and conduction effects of traversed material. They indicate definite reduction here of energy loss in condensed matter, in good agreement with stopping experiments of Pomerantz and Johnson (*34*) (for mesons of 1,000 Mev in water and lead) and of Crane, Oleson, and Chao (*35*) (for electrons of 10 Mev in carbon). In comparison with the Bethe-Bloch for-

mula (*36*), Figs. 5 and 6 are those given by Halpern and Hall to indicate the reduction in ionization loss. Hereford (*37*) has confirmed the theory of Halpern and Hall experimentally with the finding of a reduction of energy loss of approximately 8% by 1-Mev electrons in carbon due to polarization effects. In a second publication, Hereford (*38*) described results with electrons of a more extended energy range—from 0.2 to 9 Mev—and again reported reduced losses in condensed matter consistent with the theory of Halpern and Hall. Incidentally, Rathbeger (*39*), using beta rays from RaD and RaE, has reported no difference in absorption or scattering through cold-rolled or annealed aluminum foils.

Many workers do not report limits of experimental error in connection with absolute stopping power measurements, but 5 to 10% accuracy appears to be the usual order. This, then, implies a net possible error of approximately 10% in an experimental evaluation of relative stopping power at any one particular energy.

There may be an additional error involved in the measurement of absorbed energy by a cavity ionization chamber if the assumption is made that the relative stopping power value employed is independent of energy. Figure 7 shows the energy dependence of relative collision losses from 10 kev to 100 Mev as given by the best available theoretical data. The ordinates of the curves of Fig. 7 were obtained by using the values for absolute losses given by Halpern and Hall (loc. cit.) for carbon, water, and lead from 100 kev to 100 Mev, and the values given by Bethe (*Handbuch der Physik* **24/1**, page 522) for air up to 100 Mev and for carbon, water, and lead below 100 kev. Only five points have been used for each curve, and the intermediate courses have been arbitrarily filled in smoothly. This is adequate because we are interested for

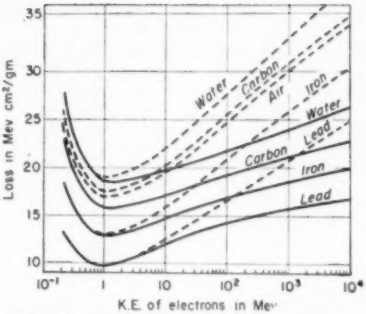

FIG. 6. Electron collision losses vs. kinetic energy. Solid curves: Halpern-Hall; dotted curves: Bethe-Bloch

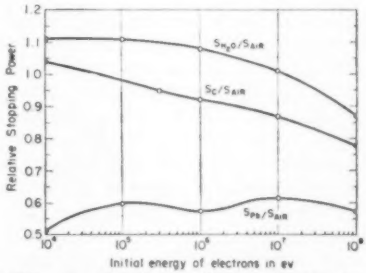

FIG. 7. Relative collision losses by electrons as a function of energy

the present only in over-all trends. The water-air and carbon-air plots indicate $\leq 20\%$ differences between extreme values over the ranges shown.

The Quantity W

The quantity W which appears in the Bragg-Gray relation is defined as the average energy transfer in the creation of an ion-pair within the cavity gas, that is, as the differential quantity dE/dI. This can be determined in at least two ways:

1. from the ratio $(dE/dx)/(dI/dx)$.

2. by a difference or differential process from experimental values of $\bar{W}$, where $\bar{W}$ represents the average energy expended per electron by an electron beam of initial energy E in the

TABLE 2
Computed Values for $\bar{W}$

E ev	dE/dx ev/cm air	dI/dx ion-pairs/ cm air	$(dE/dx)/(dI/dx)$ ev/ion-pair
10^4	25,200	1,050	24.0
10^5	4,750	150	31.6
10^6	2,190	50	43.7
10^7	2,520	54	46.7

production of an ion-pair while the electrons are being brought to rest.

In Table 2, W for air is computed as the ratio $(dE/dx)/(dI/dx)$, where the values of dE/dx are those provided by Bethe (loc. cit.) and the values of dI/dx are those given by Gentner, Maier-Leibnitz, and Bothe (*40*).

Gray, (*1, 41*) has listed much of the work on the experimental evaluation of $\bar{W}$ up to 1944, and since that time there has appeared a related report by Nicodemus (*42*). What is apparently the most reliable value of $\bar{W}$ for air published to date is that of Gerbes (*43*). Gerbes' work represents a combination of a refinement of the previous careful work of Eisl (*44*) and adjustment of an empirical curve to fit the experimental results of Pigge (*45*). Gerbes' value is

$$\bar{W} = 31.62 + \frac{5.27}{\sqrt{E - E_I}} \pm 0.08$$

electron volts per ion pair where E is the initial energy of the electrons in kev (between 0.3 and 60) and E_I is the ionization potential of air (1.7×10^{-2}) in kev. This relation, plotted in Fig. 8, typifies the trend obtained by other workers: relatively high values of $\bar{W}$ and strong dependence on energy for electrons of low initial velocity, and constancy at around 32 volts per ion-pair for electrons of high initial velocity. Freund (*46*), who followed the course of $\bar{W}$ down to initial velocities just above ionization potential, gives a figure of 57 volts per ion-pair for the lowest initial energy electrons. For the low initial velocities there are large discrepancies in the value of $\bar{W}$ among individual experimenters. However, at the higher energies, there is general agreement to within a few per cent.

W can be determined from the data of Gerbes for $\bar{W}$ through the relation

$$W = \frac{\bar{W}^2}{\bar{W} - E\dfrac{d\bar{W}}{dE}} \qquad (7)$$

Equation 7 follows directly from the defining equations

$$\bar{W} = \frac{E}{I}, \qquad W = \frac{dE}{dx} \Big/ \frac{dI}{dx} \text{ and}$$

$$I = \int \frac{dI}{dx}\, dx$$

Putting Gerbes' empirical relation for $\bar{W}$ into Eq. 7, one obtains

$$W = \frac{\left(31.62 + \dfrac{5.27}{\sqrt{E - E_I}}\right)^2}{31.62 + \dfrac{7.91}{\sqrt{E - E_I}}} \qquad (8)$$

Gerbes (*43*) has carried out the computation of Eq. 8. His values for W are plotted in the lower curve of Fig. 8.

The values of W given in Fig. 8 are preferable to those which were indicated as obtained from the ratio $(dE/dx)/(dI/dx)$, because only the former values are consistent with the established experimental results on $\bar{W}$.

In a later paper (*47*) Gerbes has extended his treatment to provide values of W for several different gases.

For high-energy studies where pairs

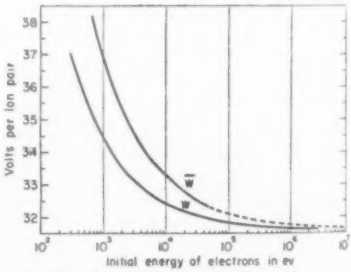

FIG. 8. Absorbed energy per ion pair as a function of energy

are involved, the positrons are usually regarded to exhibit energy loss behavior identical with the electrons. This is consistent with limited experimental work along these lines (*48*, *49*), but it is at variance to the findings of Seliger (*50*), who observed an appreciable difference in backscattering for positrons of Na^{22} and for electrons of I^{131}. Heitler (*51*) indicates that annihilation probability slightly reduces the average range of fast positrons as compared with the range of equivalent energy electrons, but the difference is not enough to explain Seliger's results. Seliger calls attention to the relativistic treatment of Coulomb scattering which yields an increase of electron scattering and a reduction of positron scattering as compared with the Rutherford formula (*52*). He further notes that this treatment yields a Z-dependence of scattering not shown by observations.

The Quantity J

In Eq. 1 the quantity J means the number of ions *formed* per unit volume. This may differ from the number of ions measured. Some of the special problems in the evaluation of J are insulation leakage, recombination, and ionization by collision—the last meaning ionization which results from the collision of ions being drawn toward the collector by an electric field.

The geometry of the chamber must be such that: 1. the desired electrical condition, for example, saturation, exists at every portion of the cavity volume, and 2. no extraneous current flows in parallel with the internal ionization current. This requires careful study of electric and radiation fields in and about the chamber and its leads.

The conventional thimble-type chamber exhibits a directional effect because of the cylindrical geometry of the chamber. Also, with the present practice of using polystyrene instead of amber in the stem, insulation leakage within the stem limits exposure of the stem to short periods and weak intensities of radiation. In certain cases a lead shielding on the stem may be employed to effect a reduction of the radiation intensity reaching the insulator without causing significant scattering into the chamber proper. But the shielding produces enhanced scattering into any immediately adjacent material and so could be unsuitable for applications wherein the chamber is surrounded by test objects, for example, in some studies with mice or drosophila.

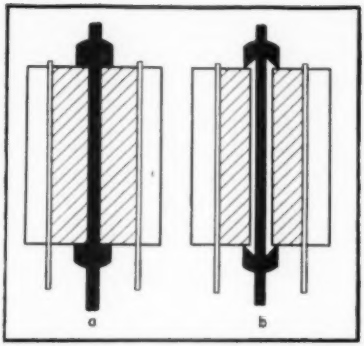

FIG. 9. Electrode insulator bushing designs. (a) typical; (b) Winogradoff

Sievert (*53*, *54*) has proposed an interesting alternative chamber design. Sievert's chamber consists of a pair of concentric conducting spheres with an air space between them, with separation maintained by three small amber spacers. The chamber can be detached from the associated electrical apparatus and exposed independently in the X-ray beam. Any support employed would then have no electrical connection with the ionization cavity.

Winogradoff (*55*) has recently reexamined the problem of the "soaking in" of charge into insulators. He has devised a method of greatly diminishing this effect by suitable design of the electrode assembly (Fig. 9). This design considerably reduces the area of

contact between electrode and insulator while maintaining mechanical strength.

At least three modern types of machine produce X-radiation output intensities of such magnitudes that, with an ordinary cavity-type chamber exposed to the beam, it is difficult or impossible to prevent the occurrence of recombination within the cavity. One such machine is the beryllium-window low-voltage X-ray unit which yields continuous outputs near the window of the order of 10^6 r/min. Another such machine is the Marx impulse generator applied to a cold-cathode tube, which can yield single pulse outputs of approximately 0.01 r with a microsecond pulse, corresponding to a peak output of the order of 10^6 r/min. A third machine is the multi-million-volt accelerator of the betatron or synchrotron type which provides indicated average intensities of the order of 100 or 1,000 r/min. If one considers an average output of 100 r/min with a pulse duration time of 10^{-6} sec and with a pulse repetition rate of 100 sec^{-1}, one obtains an average output during each pulse of 10^6 r/min.

Comparative Methods

One of the very few absolute experimental checks which has been performed to date is provided by a comparison of Gray's cavity-chamber determination (*56*) of 8.3 ± 0.2 cal/gm/hr for the total energy absorbed from the γ-radiation from RaC in equilibrium with RaB, and Zlotowski's microcalorimetric determination (*57*) of 9.1 ± 0.15 cal/gm/hr for the same quantity. The difference from the mean of the two independent figures is 5%, and the difference from each other is 10%. However, Gray estimates that Zlotowski's figure conceivably may have been in error sufficiently to reduce the calorimetric result to 8.9, and that his own (Gray's) value may have been in error sufficiently to raise the cavity-chamber result to 8.7. (The cavity-chamber figures are based on the values of 32.5 volts per ion-pair for W and 0.93 for the relative electronic stopping power of aluminum and air. Gray's ionization measurement was made in aluminum.)

For the determination of energy absorption, the calorimetric technique is attractive in principle, but the low sensitivity of the method has discouraged its use in practice. However, by resorting to low temperatures, one can conceivably achieve sufficient sensitivity to justify consideration of the calorimetric method, at least for use in a reference standard. The sensitivity gain at low temperatures is the result of the corresponding reduction of specific heats. The selection of the optimum operating temperature is set by:

1. Specific heat (proportional to T^3).
2. Radiation losses to surroundings (proportional to T^4).
3. Problems of production of low temperature.
4. Problems of thermometry.

The first two items indicate a strong advantage of going to the lowest practicable temperature. The last two items set the lowest practicable temperature at the present time at 77° K, the boiling point of liquid nitrogen at atmospheric pressure. In a liquid nitrogen calorimeter similar to the one described by Scott et al (*58*), currently in operation at the National Bureau of Standards, it is possible to hold the temperature error to 0.0001° per minute. This implies a 1% error in the measurement of the temperature rise in graphite from an X-ray beam of 100 r/min.

An excellent review of calorimetric work has been given by Myers (*59*). Some further experimental approaches to local energy measure which appear to be sufficiently attractive to merit consideration are: examination of color centers in crystals, quantitative chemical measure to response to radiation energy, and observation of fluorescence

in solid or liquid detectors. Some preliminary color center studies on radiation energy absorption have been described by Alger (*60*) and by Berger and Paul (*61*). Chemical measures of X-ray energy absorbed have been proposed by Day and Stein (*62*) and by Taplin and Douglas (*63*). And a recent report involving fluorescence indication of X-radiation has been given by Cassen and Curtis (*64*).

* * *

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WHAT ARE THE PROSPECTS FOR

Here are two commentaries, the first a very pessimistic one on the development of industrial nuclear power; the second a specific suggestion on how government participation might make industry's use of nuclear power practicable. Important factors involved in determining whether or not power will be feasible are the cost of chemical process-

Dismal—too many stumbling blocks

says EUGENE AYRES
Gulf Research & Development Company
Pittsburgh, Pennsylvania

MUCH HAS BEEN WRITTEN about the possibility of competitive nuclear power for the future. All of such studies are necessarily speculative and range from highest optimism to the deepest pessimism. For no one today can have the prescience to appraise inventions and discoveries that have not yet been made. All that can be done at this time is to paint the picture with the colors of our present conception of nuclear technology. With this picture, each one of us can use his imagination to reach his own conclusion.

It is necessary at the outset to have clearly in mind the great difference between energy for useful power and energy for destruction. If, for instance, an automotive engine could be designed to operate with nitroglycerine, we would complain bitterly about miles per gallon with such a fuel. A pound of gasoline contains six times as much energy as a pound of nitroglycerine. The earth is struck by lightning about a hundred times per second. But the energy represented by the whole of the electrical potential gradient between the earth and the atmosphere is only about a third of the present world consumption of energy. (Incidentally, no one has an idea for the utilization of any of this electrical energy.) The violence of the lightning disguises its weakness.

It would require the fission of about 1,300 atomic bombs to generate as much heat as the wood that is being burned annually in the United States. To equal all of our industrial energy consumption, we would have to explode an atomic bomb every 24 minutes. How many months would it take to use up all of the atomic bombs (or the equivalent in fissionable material) that will ever be made in the history of the human race? Of course, no one can answer this question. There are too many "unknowns."

Geochemists have a pretty good idea of the total amount of uranium in the

(Continued on page 74)

Eugene Ayres, a petroleum chemist, is a recognized authority on energy resources. As such, his viewpoint on industrial nuclear power is broad and impartial. He is technical assistant to the executive vice president of the Gulf Research & Development Co.

INDUSTRIAL NUCLEAR POWER?

ing, the availability of raw material, and the cost of obtaining it in sufficient quantities. According to the plan proposed in the second commentary, the high cost of the power produced could be offset by a fee paid industry by the government for the plutonium also produced in industry-built-and-owned reactors operating on government-leased uranium

Good—here's a plan to consider*

says CHARLES ALLEN THOMAS
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OUR PRESENT atomic program, other than weapon research, should be made more attractive to industry. It should be made so attractive that industry will place its best resources into research and development work which eventually will pay dividends to the stockholders, corporate as well as national. By this method, we can create competitive development, and the program's progress will be accelerated.

In this connection, I propose below a concrete example of how atomic power could be developed in this country within the framework of our industrial pattern.

First of all, industry is interested in whether atomic energy can produce power comparable in cost to coal or water power. We know that this is not possible at the present technological stage of atomic progress. But the plan which I propose contemplates the design, construction and operation of an atomic power plant built by industry with its own funds, producing power and plutonium in the same plant.

The uranium, the necessary source of power, would be loaned or leased by the government to the industrial plant, which would convert a portion of it into plutonium and power. The power would belong to the industry that put up the money, but the plutonium and the isotopes and all the fissionable by-products would at all times belong to the government.

Let us assume, for example, that a 75,000-kw power plant were placed in Idaho, where the power could be used in making elemental phosphorus. Phosphorus is a very important element to our national life and the present deposits in Tennessee and Florida are being depleted. However, there are ample phosphate deposits in our western

(*Continued on page 77*)

Charles Allen Thomas, who is executive vice president of Monsanto, was the wartime director of Clinton Laboratories at Oak Ridge. He later aided in the preparation of the Acheson-Lilienthal report and the Baruch plan for international control of atomic resources.

* EDITOR'S NOTE: Dr. Thomas' plan for industrial development of nuclear power was presented in a commencement address at Hobart and William Smith Colleges, Geneva, New York, on June 11, 1950.

Prospects for Power—

by Eugene Ayres

(*Continued from page 72*)

earth's crust, but they do not know how it is disposed. There is no possible way of estimating what can ultimately be recovered except in regard to "order of magnitude," and even this must be based upon many assumptions. A few of the problems in making such an estimate are as follows:

1. Should we count the commonly occurring U^{238} *or only the* U^{235} (which would represent about 0.7% as much total energy)? This depends upon the practicality of the "breeder" operation.

2. What is the lowest limit of uranium concentration that can be worked? Unless new flotation methods can be discovered, the cost of recovery of uranium will increase roughly with the reciprocal of the square of the concentration in the ore. And, below some critical concentration, more energy would be required for recovery than could be generated by fission. No one can say now what this critical concentration is because no one knows what the net nuclear power yield would be.

3. How much of the world's resource of uranium ore of recoverable quality is likely to be found? The world-wide abundance of fissionable elements is offset by attenuated distribution. Petroleum forms subterranean pools that can be tapped. Coal forms great continuous deposits that can be mined. But uranium ores, in the higher concentrations, frequently occur in lenses. And the lenses are little things that you can lift with one hand. When a piece of ore is found, the prospector naturally expects to find other pieces in the same locality, but usually he is disappointed. Exploration is difficult in spite of the Geiger counter. If the instrument is sensitive enough to detect ores of moderate concentration under even a few feet of overburden, it is likely to be oversensitive to background radiations. So far, an extremely small supply of concentrated ore has been found, and it is generally believed that we shall have to depend upon deposits that contain less than a pound of uranium per ton of ore. The recovery of uranium from such low-grade sources as shales, phosphates, and lignites, is a problem that has not yet been solved. All that can be said of the operation now is that it *may* be *technically* possible.* If so, there still remains the problem of cost.

Assumptions and Operations

To construct any picture at all of industrial nuclear power, it is necessary to assume: (*a*) that ordinary U^{238} can be used (no one can envision the civilian use of nuclear power unless the "breeder" operation is successful); (*b*) that uranium can be recovered at reasonable cost from ores containing one pound per ton (otherwise we would not have enough nuclear fuel to justify development); and (*c*) that most of the deposits of this sort can be discovered. Many will say that no one of these assumptions can reasonably be made at this time.

Inasmuch as no one can say at this time what definite steps may be required for the optimum development of nuclear power, it is necessary to assume the steps which are now used for the manufacture of fissionable material for bombs. A few of these steps might be eliminated through further research.

As far as we know now, eleven steps are needed to accomplish nuclear-power generation:

1. Separation of the uranium from the ore.

2. Purification of the uranium compound. This is important because the

* "Atomic Energy and the Physical Sciences," U. S. Atomic Energy Commission (January, 1950).

presence of impurities that would capture neutrons would be intolerable. The degree of purity must be high.

3. Reduction of the uranium compound to metal.

4. Fabrication and machining of the uranium metal into long cylindrical rods.

5. Jacketing of the rods with aluminum to protect the uranium from corrosion by water and air in the plutonium-producing reactor.

6. Operation of the reactor. The design of the reactor will have to represent a compromise between what is believed to be best for power generation and what is believed to be best for the efficient conversion of uranium to plutonium. We must assume that a satisfactory compromise can be found.

7. Removal of heat from the reactor to a power generation system. Molten metal will be used. This heat-transfer metal must be fairly light, must remain in a liquid state over a wide range of temperatures between a low melting point and a high boiling point, must have good heat-transfer characteristics, and, above all, must have the proper nuclear characteristics. We must assume that suitable alloys can be found.

8. Removal, after a considerable time, of the uranium rods from the reactor for chemical processing. This must be done after only a very small percentage of the fuel has been consumed.

9. "Cooling" of the radioactive rods —a time of storage to permit the high level of radioactivity to subside.

10. Chemical processing of the rods. This is the major step and will represent probably 80% of the cost of the power plant. The beautifully machined and jacketed rods must be completely dissolved in chemical reagents. In the first reagent, only the jacket is removed. The second reagent dissolves everything else, and this solution is processed to obtain pure uranium, pure plutonium, and about forty other elements as free as possible from uranium and plutonium. The great bulk of the product, uranium, is then put back into the third step in the process (reduction to metal), and then through all the succeeding steps (fabrication, jacketing, etc.). The plutonium is stored as active fissionable material. The forty impurities are radioactive and must be disposed of in special ways.

11. Disposal of the radioactive wastes. This is a problem that has not yet been satisfactorily solved. So far, the nonvolatile products of fission have been stored. Some of the elements lose their dangerous radioactivity in a few hours while others are dangerous for many years. Even in the manufacture of atomic bombs, an operation whose requirements have been negligible in magnitude compared to those of industrial power, the storage has become embarrassing. Some of the short-lived materials can be diluted and run into streams but, in spite of precautions, the mud of such streams can retain and build up the radioactivity. Gaseous wastes are discharged to stacks from 200 to 300 feet high. The waste-disposal problem is helped somewhat by increasing by 60 days the "cooling" period between the time the rods are removed from the reactor and the time the chemical processing begins.

The continuous generation of nuclear power is thus a process in which 95% or more of the nuclear fuel must be continuously recycled through the most costly and complicated chemical process now known and through a high-grade machine shop. The cycle must be made many months long because of the time it takes to react, to "cool," and to repurify.

Expensive Removal of Impurities

There are two reasons for the costly nature of the nuclear chemical plant. Both have to do with poisons.

One problem is that of avoiding the

"poisoning" of the nuclear reaction itself—the accumulation of the forty or more elements that slow down and finally stop the formation of plutonium. In most industrial operations, the removal of reaction poisons is relatively simple. Catalysts, for example, can be regenerated at intervals *in situ* or even continuously. The ashes from fuel combustion can be shaken out. In other processes, volatile products can be distilled off, and insoluble products can be precipitated. Many processes depend, for their economic status, primarily on the difficulty of eliminating the things that interfere with reaction. In the nuclear power plant everything is against economic operation. Nothing can be done in the reactor itself to remove impurities. The entire charge must be removed and processed, not by simple operations such as heating or cooling or gas blowing, but by a nightmarish succession of chemical engineering steps taken only after a long "cooling-off" period.

In most industrial operations, the ratio of recycled material to fresh charge is less than unity. This recycle ratio is the major factor in determining capital costs because it determines the capacity of equipment for a given input of raw product. In certain petroleum processes, the capital cost is regarded as excessive if it is necessary to recycle more than five times the volume of the charge. But for plutonium manufacture the recycle of uranium amounts to more than twenty times the rate of fresh uranium input. If yields could be disregarded and the operation could be carried out as a once-through process, the chemical plant and reactor, per pound of converted uranium, would be only one twentieth as large as it now needs to be.

An additional complication is that all stages of plutonium manufacture must be carried out by remote control.

These are some of the factors that sky-rocket the cost of getting rid of the reaction poisons.

The other "poison" problem is, of course, the matter of waste disposal. There is no practical way of speeding up radioactive decay. We simply have to "stand and wait" for days or decades.

The cost of power to the consumer is made up of various items, the largest of which are fixed by the investment. Water costs nothing, but hydroelectric power is usually as costly as coal-steam-electric power because the higher investment in the hydroelectric plant offsets the cost of coal. It has been estimated that if nuclear fuel could be made without cost, and used in a conventional power plant, the cost of the resultant power to the consumer would be about 75% of what it is now. But it cannot be used in a conventional power plant. The extra investment required for its use would insure a *higher* cost to the consumer even if the nuclear fuel itself cost nothing. But nuclear fuel cannot be made without cost.

Conclusions

We are forced to the conclusion that even if all of the technological stumbling blocks are removed, nuclear power will be sure to cost a great deal more than power from hydroelectric plants or from steam plants with fuel costs many times what they are now. This is evident when we think of the relationship between the probable cost of the entire plutonium manufacturing plant and the cost of a conventional boiler furnace. All of the power equipment after the steam plant would be common to both the steam and the nuclear installations.

There are far too many questions that have not yet been answered to make any quantitative estimates of the cost of a nuclear-power plant. But it is useful to make the following comparison:

A plant for the manufacture of 200,000 tons per annum of Buna S would cost about $120 million. The

part of the plant devoted to the production of the steam and electric power for the operation of the processing steps would cost about $10 million—about 8% of the total. In a nuclear power plant, the steam and electric power facilities to generate salable power would constitute a minor proportion of the total plant—the major proportion being devoted to the manufacture of plutonium. Estimates for power facilities have been made ranging from 5% up to 20%. It would seem that we could not be too far wrong if we took the Buna S 8% (almost any large chemical plant would be similar) and assumed that a nuclear-power plant costing $120 million would include a $10 million investment in power facilities. If we assume that none of the power produced was required to operate the plutonium plant, we could count on a salable output of around 100,000 kw—a power output of moderate size. (The power rating of the Oak Ridge reactors is reported to be 2,000 kw.) The interest and depreciation charges on a $120-million investment in the one case would be applied against 200,000 tons of Buna S while, in the other case, they would be applied against 100,000 kw. In the first case, we would have a chemical plant turning out chemicals. In the other case we would have a chemical plant turning out power. The net salable power would be, of course, the difference between the total power generated and the power required to operate the plant.

The example is faulty in that $120 million would probably not be nearly enough for a plutonium plant of optimum size. At the present time the optimum is anybody's guess. The reactors are "extremely costly,"* for example, and yet they are said to amount to only about a fifth of the cost of the chemical part of the plant. But the ratio of power facilities to total facilities should not vary greatly with size.

In view of the fundamental difficulties outlined above there would seem to be good reasons for predicting a dismal future for industrial power from nuclear reactions. More attractive possibilities will depend, perhaps, not on the solution of present problems, but rather upon the solution of problems that have not yet been conceived.

* Lawrence R. Hafstad. Reactor program of the Atomic Energy Commission, *Chem. Eng. Progress* (February, 1950).

Prospects for Power—

by Charles Allen Thomas

(*Continued from page 73*)

territory, but the deterring factor to industry is the lack of power for electric furnace operation. Let us suppose that an industry would put up its own capital for such an atomic-power plant. Both power and plutonium would be produced simultaneously from the uranium fuel.

The fuel, i.e., uranium, before going into a nuclear reactor, is put in metal cans which are then inserted into the reactor. This canned fuel could be sent under guard by the government to the industrial plant, where a small portion of the uranium is converted into plutonium. After conversion, these containers are removed from the pile. The government would then transport these same containers to the government chemical plant, say Hanford, for plutonium extraction and purification.

Industry would receive a fee from the government for converting a portion of the uranium into plutonium, and that

fee which industry receives would offset the high power cost. The cost of this power then would be within the range which would attract industry to make this large capital investment. Some calculations and discussions on this subject with colleagues lead to the belief that such a plan is economically sound. Industry would get power at a price attractive enough to venture its investment, and the government would get its plutonium at a price cheaper than it is now making it at Hanford. The same bookkeeping applies in both cases. More important, we will have industry in there trying to cheapen costs, improve yields, and design low-cost plants. Thus competitive progress is made.

Several plants would then be producing plutonium. We would have dispersed, as we are told national interests of security require, one of our most vital industries—one that means so much to our national safety. In the event of total war, a greater segment of American industry will have been well-schooled in this technology.

It is heartening to see that the Atomic Energy Commission has cleared up one point on patents. Now, if, under such a scheme as proposed, industry invents processes or means for lowering the cost of plant operation, it is permitted to take out patents on the processes with the understanding that in time of emergency all of this information would be available to the government.

Long-term Contracts

This proposition should be open to all responsible industries who need the power and are willing to venture their capital to do it. The government would have to make it attractive by giving private concerns a long-term contract so that the capital could be amortized. The industry, on the other hand, must assure the government that the plant and operations are carried out under their standards of security and health.

Calculations show that the capital cost for an atomic power plant today is of the order of 2½ times the cost of a conventional power plant with coal. As I have said, the fee for the plutonium would help offset the increased power cost and would result in cheaper manufacturing cost of plutonium and its by-products to the government.

In a plan like this, it would seem that the information about design, engineering, and construction of such a plant would pass along a two-way street between industry and government. Industrial engineers would seek government knowledge and experience that now exists, and at the same time the over-all program of the Atomic Energy Commission would be furthered.

The matter of security could be amply handled. If at any time there were any suspicions that critical materials were being misused, the government could stop the power plant immediately by stopping the supply of uranium. (There is a precedent for this in the narcotics industry. Certain chemical and pharmaceutical firms operate under government control in somewhat the same manner.) It would be understood that at all times the plant activities would be under government inspection.

If this plan were put into effect, which I think it could be, the main difficulty would be to sell industry on putting up capital. But if the terms of the government contract were of long enough duration and of such a nature that a partnership principle were the over-all philosophy, I believe government and industry would mutually benefit. Each new plant would be a source of strength in peace or war.

BOOKS

The Transuranium Elements (Div. IV., Vol. 14B, of the National Nuclear Energy Series), edited by Glenn T. Seaborg, Joseph J. Katz, and Winston M. Manning, McGraw-Hill Book Co., Inc., New York, 1949, Parts I and II, 1733 pages, $15.00. *Reviewed by R. Spence, Director, Chemistry Division, Atomic Energy Research Establishment, Harwell, England.*

Out of the great mass of new knowledge and new accomplishments which arose in connection with the development of the atomic bomb, the synthesis of a group of artificial elements, additional to the 92 known terrestrial elements, is perhaps the most striking achievement. The research papers concerned with the discovery and investigation of these elements have been collected together in this volume of the National Nuclear Energy Series.

The editors state that the papers are intended to be of the same type as those ordinarily appearing in scientific journals. This standard has, in general, been well maintained. In fact, the standard often seems surprisingly high when it is remembered that most of the work was carried out under conditions of exceptional secrecy and compartmentalization, with the pressure of a war-time technical program behind it.

Part I begins with an account of the discovery and separation of neptunium and plutonium and of their general chemical and nuclear properties. Then follows an impressive group of about forty papers dealing with the physical chemistry of aqueous solutions of plutonium and covering such aspects as electrochemistry, absorption spectroscopy, valency states, kinetics of interchange of valency states, hydrolysis and complex ions. This section is valuable, first, as an excellent example of the application of well-established physicochemical principles to the case of one particular element, and, second, as a detailed account of the behavior of aqueous solutions of a polyvalent heavy metal. Approximately twenty-five articles are devoted to dry chemistry studies of plutonium halides, oxyhalides, oxides, peroxides, etc., and include some interesting vapor pressure investigations. This general topic is continued in the first fourteen articles of Part II. Many of them are particularly concerned with thermodynamic properties and include some useful experimental details, as well as a description of a precision semi-micro calorimeter.

Most of the radiochemical studies seem to have been collected in the remainder of Part II, though not in any noticeable order. A group of papers on the nuclear properties and chemistry of neptunium is followed by articles on the preparation of thin films, on alpha counting and backscattering, and a 48-channel pulse analyser. The nuclear properties of a number of isotopes of radium, actinium, thorium, protactinium, and uranium are the subject of about fifteen papers, and there is a rather isolated but important batch of eight papers by W. H. Zachariasen dealing with the X-ray crystallographic studies of neptunium and plutonium compounds. In addition to six papers on americium and curium found somewhat dispersed in this section, there is also an important article by Dr. Seaborg, in which the electronic structure of the heaviest elements and their place in the Periodic System are discussed. The evidence relating to the filling up of the 5*f* electron shell has been carefully marshalled and little room is left for disagreement with the conclusion that although a 5*f* electron may not necessarily be found in thorium compounds, or indeed in protactinium, the series can

nevertheless be properly termed an actinide series. The production, by cyclotron bombardment, of a number of new isotopes of neptunium and plutonium is described in the last section of Part II which concludes with two reports on the determination of the specific activity and half-life of radium and plutonium respectively.

These volumes give an impressive picture of a great effort. They are a mine of valuable information not only for radiochemists, but also for nuclear physicists and for physical and inorganic chemists. It is a great pity, therefore, in the reviewer's opinion, that an index has not been included.

Experimental Designs, by W. G. Cochran and G. M. Cox, John Wiley & Sons, Inc., New York, 1950, ix + 454 pages, $5.75. *Reviewed by Cuthbert Daniel, Consultant Engineering Statistician, New York, N. Y.**

The ideas of R. A. Fisher on the design of complex experiments were developed in parallel with his discoveries in theoretical statistics. They were first systematically stated in his book, "The Design of Experiments" in 1935. The principles announced were applied at that time principally in genetics and in experimental agriculture. The intervening period has seen the rapid spread of the original ideas to research in pharmacology, textiles, medicine, and chemical engineering.

It is the purpose of this review to raise the question: Is the statistical design of experiments an applicable technique for some of the problems of the nuclear physicist, the nuclear chemist, the nucleonics engineer, the nuclear biologist? If the answer to any part of this question is "yes," or even "possibly," then the book under review is strongly recommended.

The methods offered are demonstrably more efficient than the classical method of holding all independent variables constant except one at a time, when

a. it is important or necessary to investigate the simultaneous impact of several variables, each over some considerable range, and/or

b. duplicate experiments do not reproduce themselves exactly, thus revealing the existence of a set of uncontrolled factors influencing the results.

Do these conditions exist in fields of interest to readers of NUCLEONICS? The reviewer does not know, but guesses that they do. If so, then it is likely that the conditions of orthogonality, of unbiasedness, of unbiased error-estimate, and of efficiency can probably all be met. In such cases, greater validity as well as greater precision can generally be guaranteed.

The title "Experimental Designs" probably deliberately parallels Fisher's classical work, since it is a major milestone on the same route. The first book laid down the principles; the second is an atlas of designs constructed according to the principles. The book assumes some familiarity with the technique of the analysis of variance. But even as a first reader, it is to be recommended for its clarity, unpretentiousness, and painstaking attention to logical detail.

Starting with a number of entirely unassailable, though often forgotten, precepts on scientific experimentation, the book proceeds to arrangements of increasing complexity. The chapters on Latin Squares, Factorial Experiments, and Lattice Squares (numbers 4, 5, and 12) will probably be of most immediate interest to nuclear scientists.

It is not easy to account for the

* Mr. Daniel was in charge of the statistical interpretation of engineering data at the gaseous diffusion plant at Oak Ridge, Tennessee during the period 1945–47.

tardiness of physical scientists in adopting modern statistical methods. This negligence may be due to some confusion concerning the actual reference of the term. It should be pointed out that the methods under discussion here have little or nothing to do with "counting statistics," with statistical mechanics, or with the Uncertainty Principle; nor do they require large numbers of observations. It is to be hoped that some few nuclear scientists, used as they are to new and difficult tools, will be willing to make the investment in imagination and in effort that will be required in order to explore and judge the usefulness of this one.

Elementary Pile Theory, by Harry Soodak and Edward C. Campbell, John Wiley & Sons, Inc., New York, 1950, ix + 454 pages, $5.75. *Reviewed by Frank C. Hoyt, Director, Division of Theoretical Physics, Argonne National Laboratory.*

It is now three years since the lectures on which this volume is based were delivered at the Oak Ridge Training School. The present publication in book form, unfortunately, adds nothing to the content of the first declassified issue of these lectures which appeared in the fall of 1948 as an AEC document and has since that time served as a standard reference in reactor theory. There has been, at the most, a smoothing over of the text in spots and correction of obvious misprints.

The ground covered, in a simple and somewhat formal mathematical style, is that which is essential to an understanding of the basic equations governing the diffusion and slowing down of neutrons, together with a rather brief discussion of pile control and kinetics.

The discussion of the two-group method for treating reflected piles is particularly to be commended and is not readily accessible elsewhere. Comparison is inevitable with the only other existing connected treatment of pile theory in the open literature, namely, the chapter by F. Friedman in the book, "The Science and Engineering of Nuclear Power." Much of the same ground is covered in both, though the Friedman account emphasizes physical and intuitional aspects, and the present one is more a systematic development of the mathematical theory. A notable omission in both cases, and, in fact, from the published literature as a whole, is any discussion of perturbation theory.

There is, certainly, little cause for satisfaction with the present state of the open literature on reactor theory. What is available in properly edited and correlated form is only a fraction of what could be covered under even the present declassification policy.

BOOKS RECEIVED

Pocket Encyclopedia of Atomic Energy, by Frank Gaynor, Philosophical Library, New York, 1950, 204 pages, $7.50.

The Effects of Atomic Weapons, prepared for and in cooperation with the U. S. Department of Defense and the U. S. Atomic Energy Commission, under the direction of the Los Alamos Scientific Laboratory, Superintendent of Documents; 456 pages (1950). Bound edition (available Aug. 28), McGraw-Hill Book Co., Inc., New York, $3; paper edition (available Aug. 12), U. S. Govt. Printing Office, Washington 25, D. C., $1.25.

Radioactivity and Nuclear Physics (Second Edition), by James M. Cork, D. Van Nostrand Company, Inc., New York, 1950, xiii + 415 pages, $5.

German-English Dictionary for Chemists (Third Edition), by Austin M. Patterson, John Wiley & Sons, Inc., New York, 1950, xviii + 541 pages, $5.

CROSS SECTIONS

Shipping Container Requirements for Ra and Co^{60}

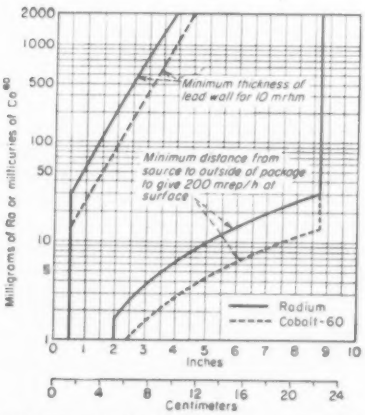
By Hanson Blatz and A. R. Piccot

Health and Safety Division, New York Operations Office, U. S. Atomic Energy Commission, New York, New York

When shipped by common carrier, packages containing radioactive materials must conform to certain regulations of the Interstate Commerce Commission (*1*). Since radium and cobalt-60 of relatively high activity are frequently shipped, specifications have been prepared in graphic form for the minimum required lead shielding as well as the size of package required to meet these regulations most economically.

Essentially, the regulations that apply (except in the special case of very small quantities of materials requiring no label) are as follows:

1. Gamma radiation should not exceed 10 milliroentgens per hour at a one meter distance from the source (10 mrhm).



Minimum lead shielding and shipping container dimensions required to ship radium and cobalt-60 sources in accordance with Interstate Commerce Commission regulations

2. Gamma radiation at any surface of the package shall not exceed 200 milliroentgens per hour.

The following assumptions were made in preparing the curves given here:

1. The radium or cobalt is essentially a point source.

2. For radium the usual radiation figure of 0.84 rhm per gram (0.5 mm Pt filtration) was used. Absorption in lead was based on Braestrup's measurements (*2*).

3. For Co^{60} a radiation figure of 1.36 rhm per curie was used. A uniform half-value layer of 1.4 cm of lead was assumed.

4. An arbitrary minimum of ½ in. was set for the lead shield.

It should be pointed out that there are other Interstate Commerce Commission regulations relative to outside contamination and total permissible quantity; these should also be followed. The curves given here are intended only as guides to lead requirements and package size.

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2. C. B. Braestrup. Protection Measurements of Lead-Shielded Radium, *Radiology* **46**, 385 (1946)

*Oxidation-Reduction Dyes as Radiation Indicators**

By Bernard E. Proctor and Samuel A. Goldblith

Department of Food Technology, Massachusetts Institute of Technology
Cambridge, Massachusetts

In the course of our researches on the application of electrons (electrostatically produced) in food processing, we have found it necessary to have a simple, rapid means of determining the extent of penetration of these cathode rays into matter. The penetration of supervoltage cathode rays into matter is a function of the accelerating voltage and the density of the material being irradiated and is expressed by the equation:

$$R_{max} = \frac{0.54\ V - 0.15}{\rho}$$

where R_{max} is the maximum range of electrons, ρ is the density of the material, and V is the accelerating voltage in Mev.

This method of determining the penetration might also be a means of determining the accelerating voltage of the electrons.

We have found that oxidation-reduction dyes dissolved in an agar gel serve this purpose. Ionizing radiations have the power of oxidizing oxidizable substances such as $NaNO_2$ and of reducing substances such as $KMnO_4$ or $NaNO_3$.

The dye resazurin, when dissolved in agar in the proportions of 8 ml of a 100 mg % solution of resazurin per 1,500 ml of agar, is converted by irradiation with cathode rays from blue to red to colorless. We have found that the amount of color change is proportional to the irradiation dosage, and that the depth of this color change in agar is a function of the accelerating voltage of the cathode rays (electrons).

We have also used methylene blue dye with equal success. However, the two-stage color change of resazurin offers advantages in that it will show the relative ionization as a function of depth, because the maximum ionization of electrons occurs in one-third of the maximum range of the electrons, and 85 % of the total dosage (or total ionization) occurs in three-fifths of the maximum range. Hence when cathode rays are applied to resazurin-agar, three-fifths of the maximum range is colorless; the remaining 15 % of the dosage (or two-fifths of the maximum range) is red tinted.

We have found this method of determining the extent of penetration of cathode rays in matter to be accurate in the range of 300- to 3,000-kv electrons. This technique has also been successfully applied to measurement of field distribution of electrons.

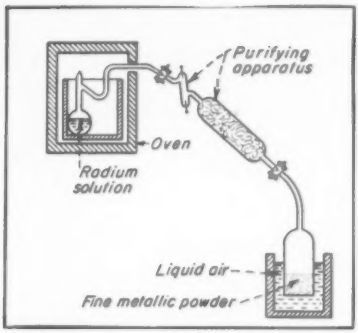
Work on the quantitative aspects of the oxidation-reduction changes involved is in progress and will be reported later.

* Received July 25, 1950.

Freeze Radon to Prepare Alpha-Ray Source

A method for preparing a homogeneous constant source of alpha rays which will be free from emanation has been patented by Marietta Blau and Boris Pregel. It is claimed that no radioactive material is destroyed in the process of preparing the Ra D-Ra E-polonium source.

A strong radium solution, such as $RaBr_2$ or $RaCl_2$ in water, is heated in an oven to promote the formation of radon gas. After passing through



purifying apparatus, the radon is collected in a freezing chamber containing a very fine metallic or plastic powder (See illustration).

The chamber and powder are maintained at a low temperature by immersion in liquid air, and the radon is therefore deposited in solidified form in the powder. The solidifying of the radon makes it possible to obtain concentrations far higher than would result from its use in the gaseous state.

The frozen emanation and powder is disconnected from the supply and allowed to stand for about three days. The radon decays in this time to radium D. With a half-life of 22 years, RaD is the mother substance of radium E, which disintegrates to polonium.

The equilibrium products of the source are not high-energy gamma emitters, and the source is, for all practical purposes, free of emanation.

The powder can be pressed or rolled onto a metal backing, or may be used in any other way desired. Since the polonium is in equilibrium with the RaD, the source will have a long life.

Use of Radioisotopes in British Industry, 1949–1950

By K. Fearnside

Isotopes Developments, Ltd., Berkshire, England

Increased industrial use of radioisotopes in Great Britain began with the first operation of BEPO, the large pile at Harwell, England, in March, 1949. Radioisotopes produced by irradiation in the pile were made available to industry. Specific activities now available for commonly used materials are shown in Table 1. In addition, some separated isotopes are also available.

To advance industrial use, the Atomic Research Establishment's Isotope Division at Harwell set up a comprehensive advisory service. In addition, the Division offered to carry out complete tracer experiments.

In the past year, over 200 firms have contacted the Isotope Division. Because industrial scientists trained in isotope techniques are in short supply, and because health hazards connected with radioisotopes have been overestimated, few of these firms have used radioisotopes.

Some industrial applications have been carried out, however. These can conveniently be divided into three groups: tracer experiments, thickness measurements, and static elimination and other problems involving the ionization of gases. Examples of British industrial effort in these fields are given in the following paragraphs.

Tracer Experiments

Oil on nylon fibers. Carrying out tracer experiments with oil is difficult because most oils do not contain any elements which can readily be made

TABLE I
Radioisotope Activities Available

Isotope	*Compound in which prepared*	*Half Life*	*Normal activity per gram*	*Energy of Radiations (Mev)*	
				Beta	*Gamma*
As^{76}	As_2O_3	26.8 h	250 mc	3.04, 2.49 1.29	2.15, 1.84 1.25, 0.57
Ba^{131}	$BaCO_3$	12 d	100 μc	None	1.2, 0.5, 0.26
Br^{82}	NH_4Br	34 h	50 mc	0.465	1.35, 0.79, 0.55
C^{14}	$BaCO_3$	5700 y	Carrier free	0.154	None
Ca^{45}	$CaCO_3$	180 d	70 μc	0.26	None
Co^{60}	Co metal	5.3 y	10 mc	0.3	1.3, 1.1
Cu^{64}	Cu metal	12.8 h	100 mc	0.58 (β^-) 0.63 (β^+)	1.2
Fe^{59}		47 d	20 μc	0.46, 0.26	1.3, 1.1
Fe^{55}	Fe metal	4 y	20 μc	None	.006
I^{131}	KI	8 d	Carrier free	0.60	0.367, 0.080
P^{32}	H_3PO_4	14.3 d	Carrier free	1.72	None
S^{35}	Na_2SO_4	87 d	Carrier free	0.170	None
W^{185}		77 d	2.5 mc	0.69, 0.48	None
W^{187}	W metal	24 h	200 mc	1.4, 0.6	0.86, 0.49

radioactive. A method for investigating variations of density of the oil used in the spinning of nylon yarn has been developed, however.

A preliminary survey showed that ethylene dibromide could be mixed with the oil in concentrations up to 5% without affecting the oil's mechanical properties. Also, comparatively little active bromine is removed during irradiation.

In an experiment with 75 denier yarn, 1% ethylene dibromide was added to the oil. Average weight of the oil was 2.5×10^{-6} gm/cm; the weight of the bromine was calculated as 2.13×10^{-8} gm/cm. The activity of the bromine after the free bromine had been removed by shaking with dilute alkali was 22 mc/gm, so that the number of disintegrations per cm on the oiled yarn was 17.3.

A photographic method of detection was used. Since the radius of the yarn is 1.5×10^{-2} cm, the maximum dose rate on a film placed in contact with the oiled yarn is 2.1×10^{-4} r/sec. Fast X-ray film exposed a few hours shows a distinguishable line whose density is proportional to activity and, therefore, to oil density.

Uneven dyeing of woolen cloth. Considerable difficulty in producing uniformly dyed cloth was encountered by a manufacturer of woolens. Before dyeing, the cloth was heavily treated with soap to remove dirt and animal oil. The soap is then removed by washing in hot water.

The uneven dyeing was attributed to incomplete removal of the soap by washing, but ordinary chemical analysis did not reveal any unusual quantities of soap present. Considering the analysis insufficient, the manufacturer decided to employ tracer techniques.

Samples of the cloth were irradiated in the Harwell pile and were then examined for half-life and radiation properties. This investigation showed that, in addition to the sodium present from the sodium oleate in the soap, there was a considerable quantity of calcium present. Table 2 shows that the sodium from the soap is not related to the uneven dyeing. There is a cor-

TABLE 2
Tracer Test on Woolens

Color of cloth	*% Ca*	*% Na*
Light red	0.350	0.0145
Dark red	0.335	0.0150
Light blue	0.380	0.0127
Dark blue	0.371	0.0125

relation between calcium content and color, however.

The calcium was believed to be deposited from the wash water. Use of presoftened water removed the trouble and produced even dyeing.

Bearing wear. Experiments with bearings consisting of 17-in. diameter cast iron bushings running on cast iron sleeves have been carried out by the Isotopes Division in conjunction with Hayward Tyler & Co., Ltd. of Luton, England. Since a bearing was too massive to be irradiated, a shim ⅛-in. thick was made and irradiated for five weeks in a flux of 5×10^9 neutrons/cm²/sec.

After allowing the activity of impurities to decay for a week, the remaining activity was almost all that of Fe^{55} and Fe^{59}. The bushing was installed on a pump and briefly run in.

With the pump's sump filled with oil, four full-load tests were carried out at different temperatures. Samples of oil were removed at the end of each test. By burning off the oil in these samples, the concentration of radioactive material was increased 2,000 times. The worn iron was left in the ash as an oxide. X-ray film was placed in contact with the ash; the blackening caused by the active material was compared with that from nonactive samples.

Using this method, wear measurements with accuracies of 0.1 to 2.5 μin., depending on the amount of ash in the oil sample, were obtained. The accuracy could be improved by taking steps to assure complete combustion during ashing, by increasing the specific activity of the bushing, and by developing the X-ray film to a higher gamma.

Thickness Measurement

A beta-ray thickness gage, consisting of a calcium-45 source mounted ½ in. from a counter connected to a rate meter calibrated in thickness, was developed by the Isotopes Division. This gage interested both the paper and plastics industries.

Ionization of Gases

In the majority of cases where sheet material is handled, unwanted static electricity is generated at some part of the process. At the best this will cause handling difficulties; at the worst, it may constitute a grave fire hazard where organic solvents are used.

Static electricity can be eliminated by ionizing the air between the charged surface and ground. In America, this is done with alpha-emitting materials; in England, not enough of this material is available for this use, and a series of experiments with beta-emitting isotopes have been performed.

Where the general difficulty is in handling—for example, paper bags, cigarette papers, and gramaphone records—a source of Tl^{204} with a strength of about 1 μc per inch run of source will eliminate the difficulty. A total of ten cases have been investigated with satisfactory results.

Where the amount of static present approaches the saturation value, as in fast-running paper machines or machines in which high polymer plastics are handled, a much greater concentration of activity is required. It would be possible to obtain such activity by the use of fission products, but sources with strengths of about 100 mc may present a very large potential health hazard, and it is very doubtful that their use would be approved.

An unusual application of ionization is being made in the metal spraying industry. In order to spray metal satisfactorily, it is essential to feed wire of the desired metal into a gun where the metal is melted and blown by a strong blast of air onto the surface being sprayed.

The melting can be carried out either by gas or by d-c electricity. If 50-cycle alternating current, the normal supply in England, is used, however, the arc between the wires strikes only intermittently. The result is a badly sprayed surface and a noise comparable to that of a machine gun.

If the arc can be made to strike at each cycle, the operation will be as smooth as that with direct current. A considerable saving in rectifying equipment can be effected. Experiments with P^{32} as an ionizing source show promise of a solution to the problem.

Use Isotopes in Australia To Study Sheep Nutrition

Acetic and propionic acids in which the carboxyl groups are tagged with C^{14} have been synthesized in Australia by the Commonwealth Scientific and Industrial Research Organization for investigations of the nutritional metab-

(*Continued on page 104*)

Practical Aspects of Surface Decontamination (*Continued from p. 54*)

with suitable detergents or reagents such as very dilute mineral acids. Strong acids and large volumes of the reagent should be avoided since these tend to soak the radioisotopes further into the surface. If these methods fail to reduce the activity to a tolerable value, chipping or grinding away the surface (with the accompanying radioactive dust hazard) is the only alternative.

Wood. Due to its inherent porosity, wood is generally less satisfactory than concrete. Extensive surface decontamination is considered to be a wasted effort. Decontamination by sanding or planing away the surface is the only alternative.

CONCLUSIONS

Many protective coatings can be used efficiently in laboratories using up to approximately 100 mc of activity in the total sample. The finished surface should be smooth, nonporous, and although chemically resistant, it should be possible to remove practically monomolecular layers by selective reagent cleaning without pitting or roughening the cleaned area. In view of the fact that susceptibility to contamination can be correlated directly with water repellency, nonwetting properties should be high on the list of requirements for a decontaminable surface.

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NUCLEONIC EVENTS

ASEE, AEC REPRESENTATIVES PLAN ADDED COOPERATION

A national Committee on Atomic Energy Education with five regional subcommittees will be formed by the American Society for Engineering Education (ASEE) under a plan for increased cooperation between engineering colleges and the AEC. The plan was developed at a meeting of the ASEE Steering Committee on Cooperation with the Atomic Energy Commission and representatives of the AEC in Washington on June 2–3.

In its report of the meeting, the Steering Committee recommended that the president of the ASEE appoint a national committee consisting of five regional subcommittees, each under the chairmanship of a member of the Steering Committee. Each subcommittee will be expected to report its activities to the Steering Committee at its next meeting in February, 1951.

The following objectives of the cooperation program were set forth at the Washington meetings:

1. To evaluate the responsibilities of engineering education in aiding the growth and development of the atomic energy industry and to determine what there is in the development of nuclear engineering which can be used to enrich and strengthen engineering education.

2. To assess the over-all needs for engineers with special training in nuclear energy.

3. To explore with AEC and its contractors subjects or fields for research which may be carried out by graduate students or engineering faculties.

4. To define the needs of educational institutions with respect to instructional materials (a) for the modification of existing courses in basic science and engineering, (b) for the modification of standard engineering curricula, and (c) for advanced training of engineers planning to specialize in nuclear energy.

5. To formulate plans for facilitating the flow of needed information regarding such instructional materials to the engineering schools.

Formation of regional subcommittees is in agreement with the ASEE's Executive Board's view that the most promising way to attain these objectives lies in regional cooperation among the colleges and between them and the AEC.

It was decided at the Washington conference that each regional subcommittee should decide on the best methods of attaining the foregoing objectives. The Steering Committee, however, recommended that each subcommittee give consideration to:

1. The organization of regional meetings attended by members of engineering faculties and representatives of AEC and its contractors.

2. Temporary employment and exchange programs with AEC laboratories.

3. Study of the needs of the atomic energy industry for engineers.

4. Study of the kinds of published materials now available relating to these applications.

5. Methods by which colleges and universities may make use of experts from AEC installations.

6. Methods by which information about engineering applications may be further identified and transmitted to

colleges and universities in a useful manner.

7. Cooperation with AEC in a program for declassification of engineering information as security permits.

Members of the ASEE Steering Committee are: Henry H. Armsby, Chairman, R. C. Ernst, O. W. Eshbach, H. B. Hansteen, M. P. O'Brien, and H. E. Wessman. Representing the AEC at the meeting were: A. H. Holland, Jr., J. C. Boyce, W. E. Kelley, M. P. O'Brien and D. W. McLenegan. Secretary of the conference was P. N. Powers.

DEAN ADVANCES TO AEC CHAIRMANSHIP

On July 11, President Truman appointed Gordon Dean to head the U. S. Atomic Energy Commission. He succeeds David E. Lilienthal who resigned the chairmanship on February 15.

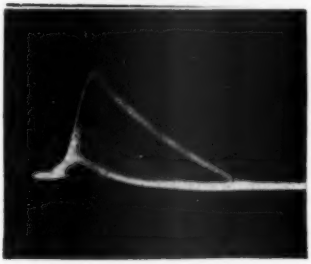
Mr. Dean had been acting chairman since June 30 in place of Sumner T. Pike, whose AEC term ended on June 30 and whose new appointment was not confirmed by the Senate until July 10. A former law partner of Senator Brien McMahon, chairman of the Joint Congressional Atomic Energy Committee, Mr. Dean was first appointed to the AEC on May 9, 1949, and on June 30, 1950, was reappointed for a new three-year term.

31 LIBRARIES TO CARRY NON-SECRET AEC REPORTS

The Atomic Energy Commission last month announced that it is placing complete sets of non-secret AEC research reports in 31 libraries in the United States. In addition, it will furnish each of the libraries with a catalog card index to the reports.

About 3,500 reports are available at present. New reports, at the rate of about 1,500 a year, will be sent to the libraries as they are issued. The 31 libraries, listed on the next page by state,

ABOUT THE COVER



REPRESENTATIVE of a new, powerful attack on gamma rays from nuclei, this month's cover shows an oscilloscope trace of the pulse produced in a scintillation counter with a NaI(Tl) crystal by gamma rays from Au^{198}. The bright band at the top, clearly separated from the continuum below, is due to the photoelectric effect of the 411-kev line in iodine in NaI(Tl). The lower broad band is due to the Compton effect in the crystal, and shows the sharp edge predicted by theory. Near the bottom, superposed on the continuum, is a 75-kev X-ray line also present in the gold spectrum of gamma rays. The sharp photoelectric line and the Compton edge permit unique measurements of the gamma-ray energy to be made. This work was done by Dr. Robert Hofstadter and J. A. McIntyre of Princeton University, Princeton, N. J. They have applied the method to other substances and have found and measured new gamma-ray lines in several substances. They have also found that pair production in the counter crystal also results in sharp lines in the pulse distributions, making a third concomitant measurement of gamma-ray energies possible. An idea of the usefulness of the method is given by the fact that the K^{40} gamma rays from a source of 10^{-9} curie have been measured. Photo from Dr. R. Hofstadter.

city, and institution, were suggested by the Board on Resources of American Libraries of the American Library Association. Each has agreed to provide full access to the reports, to give reference service, and to provide photostatic copies at established prices. The libraries are:

California
Berkeley, University of California; *Los Angeles*, University of California
Colorado
Denver, Public Library
Connecticut
New Haven, Yale University
District of Columbia
Washington, Library of Congress
Georgia
Atlanta, Georgia Institute of Technology
Illinois
Chicago, University of Chicago, John Crerar Library; *Urbana*, University of Illinois
Louisiana
Baton Rouge, Louisiana State University
Massachusetts
Cambridge, Harvard University, Massachusetts Institute of Technology
Michigan
Ann Arbor, University of Michigan; *Detroit*, Public Library
Minnesota
Minneapolis, University of Minnesota
Missouri
Kansas City, Linda Hall Library; *St. Louis*, Washington University
New Jersey
Princeton, Princeton University
New York
Ithaca, Cornell University; *New York City*, Columbia University, New York Public Library
North Carolina
Durham, Duke University
Ohio
Cleveland, Public Library; *Columbus*, Ohio State University
Pennsylvania
Philadelphia, University of Pennsylvania; *Pittsburgh*, Carnegie Library
Tennessee
Nashville, Joint University Libraries
Texas
Austin, University of Texas
Washington
Seattle, University of Washington
Wisconsin
Madison, University of Wisconsin

AEC OFFERS FELLOWSHIPS IN INDUSTRIAL MEDICINE

A fellowship program for training a limited number of industrial physicians will be started by the Atomic Energy Commission this fall, if qualified candidates can be obtained.

During the 1950–51 academic year up to four qualified candidates will be selected for academic training in industrial medicine. The stipend for fellows will be $3,600. During 1951–52 an additional year of on-the-job training at AEC installations will be offered to selected physicians who complete the first year of academic training. On-the-job training would carry a salary of $5,000 per year.

To be eligible, prospective applicants should have completed a medical course and a satisfactory internship plus one year of residency in internal medicine or its equivalent. All candidates will be required to have a full security investigation and clearance before being appointed.

Application forms for AEC Industrial Medicine Fellowships may be obtained from the AEC Industrial Medicine Fellowship Committee, Division of Biology and Medicine, Atomic Energy Commission, Washington, D. C.

ARGONNE'S RESEARCH DIVISIONS REORGANIZED

The Argonne National Laboratory, Chicago, Ill., last month announced that on July 1 its Experimental Nuclear Physics Division, Theoretical Physics Division, and Mass Spectroscopy and Crystal Structure Division were consolidated to form the Division of Physics, under the direction of Louis A. Turner, former head of the department of physics at The State University of Iowa.

Effective on the same date, all biological, medical, and radiological physics research at the laboratory was combined to form the Division of Biological and Medical Research. This division is directed by Austin M. Brues, with Hermann Lisco, L. D. Marinelli, and E. L. Powers serving as associate division directors.

OTS TO DISTRIBUTE AEC TECHNICAL REPORTS

Industry will have easier access to non-secret atomic energy technical reports under a new distribution plan announced last month by the Atomic Energy Commission and the U. S. Department of Commerce.

Under the plan the Office of Technical Services of the Dept. of Commerce will become the sales agency and reference source for non-secret AEC technical reports. The OTS has been a clearing house on other types of non-secret federal technical information since it was organized in 1946.

Sole responsibility for the preparation and release of AEC reports will continue within the AEC, which will handle distribution and exchange of publications with academic, scientific, and official institutions. The AEC will also continue to handle distribution of non-technical reports dealing with atomic energy.

In addition to AEC technical reports, the OTS will also handle subscriptions to *Nuclear Science Abstracts*, the publication providing titles and abstracts of publicly and privately published reports in the atomic energy field.

HARWELL ORGANIZES NUCLEAR PHYSICS MEETING

An international nuclear physics conference to be held at Oxford University, Oxford, England from September 7 to 13, has been organized by the Atomic Energy Research Establishment at Harwell, England. About 200 delegates from the United States, the British Commonwealth, and Western Europe will be invited to attend.

The conference will be divided into two parts. The first will be concerned with the use of high-energy particle accelerators for nuclear physics work, and the second with lower energy nuclear physics, including the use of atomic piles for experimental work. Subjects to be discussed include high-energy accelerators, experimental and theoretical high-energy physics, beta-ray spectroscopy, nuclear and pile physics, and neutron spectroscopy.

KELLEX CORP. SOLD TO VITRO MFG. CO.

The M. W. Kellogg Company recently announced that it had sold the stock and assets of its subsidiary, The Kellex Corporation, to the Vitro Manufacturing Company. Contracts currently held by Kellex, primarily in the field of atomic-energy development, will be continued by Vitro under the Kellex Corporation name.

The Vitro Manufacturing Company conducts chemical manufacturing operations for the ceramics industry and refining operations under a prime contract with the AEC. Its principal plants are near Pittsburgh, Pa.

U. OF ROCHESTER EXPANDS NUCLEAR RESEARCH STAFF

To strengthen the work of its physics department, the University of Rochester has made nine promotions and appointments.

Dr. Arthur Roberts, of the State University of Iowa, has been appointed associated professor of physics at the University of Rochester. He will teach and conduct research with the 250,000,000-volt cyclotron.

Dr. Harry W. Fulbright, formerly of the Princeton University physics faculty, has been appointed assistant professor. One of the scientists at Los Alamos during the war, he will teach and conduct research on the small cyclotron project.

Dr. Charles L. Oxley has been promoted from research associate to assistant professor, and will teach and conduct research on the large cyclotron project.

Dr. John H. Tinlot, of the Columbia University faculty, will teach and con-

duct cosmic-ray and cyclotron research as an assistant professor.

Appointed as research associates were: Dr. Richard Wilson, now at Clarendon Laboratory, Oxford University, England, to conduct research on the large cyclotron project; Dr. David M. Ritson, now at the Dublin Institute for Advanced Studies, Dublin, Ireland, to do cosmic-ray research; and Dr. James Rouvina, to conduct cyclotron research. Dr. Rouvina received his Ph. D. degree at the University of Rochester last month.

Visiting research associates for the summer of 1950 are Dr. C. H. Yang and Dr. Kenneth M. Case, both of the Institute of Advanced Study at Princeton, N. J. Both will conduct research in theoretical physics.

23 AEC-UNIVERSITY PROJECTS REPORTED IN HANFORD AREA

In a midyear report, the Hanford Operations Office of the AEC announced that 23 research projects with total commitments of $736,411 are in progress at educational institutions in that area. This is an increase of 5 projects and $474,698 over the number of projects administered by the Hanford area at the beginning of 1950 (NU, Feb. '50, page 89).

The new total sum includes both new research work and projects started under AEC sponsorship in past years.

IN BRIEF

➤India's first factory for producing uranium and thorium from monazite will start functioning in about six months, according to K. G. Menon, chief secretary of the Travancore-Cochin States Union Government. The factory is situated at Alwaye, on the west coast of India.

➤*Developments in atomic energy research as related to dentistry will be the concern of the atomic energy program committee recently formed by the First District Dental Society of the State of New York, which is affiliated with the American Dental Association. The committee, whose members are Drs. Theodore Kaletsky (chairman), Arthur E. Corby, Waldo Mark, M. E. Michaelson, Percy T. Phillips, E. G. Van Valey, E. B. Hoag, William Fennelly, Isidore Teich, and F. X. McHugh, will establish a library on atomic energy information and establish scholarships to encourage more young scientists to enter the field.*

➤The Agricultural and Mechanical College of Texas and the University of South Carolina have been elected as sponsoring universities of the Oak Ridge Institute of Nuclear Studies.

NUCLEAR NEWSMAKERS

Lewi Tonks, physicist in the General Electric Research Laboratory, has been appointed head of the Physics Division of GE's Knolls Atomic Power Laboratory at Schenectady, New York.

Lawrence A. Kimpton has been appointed vice-president in charge of development at the University of Chicago. Formerly dean of students and professor of philosophy at Stanford University, his duties will include administration of atomic energy research at the university.

Rudolph W. Landenburg, atomic physicist, retired from his post as Brackett research professor at Princeton University on June 30.

Edward A. Doisy, biochemist at the St. Louis University School of Medicine, and **Curt Stern,** zoologist at the University of California, have been appointed to the AEC Advisory Committee for Biology and Medicine. Dr. Doisy replaces **A. Baird Hastings** of Harvard University, while Dr. Stern replaces **George A. Beadle** of the California Institute of Technology.

Robert J. Speer has been named head of the radiochemical laboratory of the Texas Research Foundation. Dr. Speer was formerly with the AEC at Oak Ridge.

Lester R. Rogers has joined the staff of Ohio State University as radiation safety inspector.

Gerald F. Tape recently joined the scientific staff of Brookhaven National Laboratory. Formerly associate professor of physics at the University of Illinois, he will assist in the scientific administration of the laboratory.

A. H. Holland, Jr. has resigned as director of the AEC Office of Research and Medicine in Oak Ridge to become associate medical director of Armour Laboratories in Chicago.

Lewis L. Strauss, former member of the U. S. Atomic Energy Commission, and **Charles E. Cotting,** president of Lee Higginson Corporation, have been elected to the board of directors of Tracerlab, Inc., Boston, Mass.

The Los Alamos Scientific Laboratory has announced that the following scientists have joined their staff: **Rollon Oscar Bondelid,** who recently received his Ph.D. from Washington University; **John S. Malik,** formerly at the University of Michigan; **Benjamin C. Diven,** formerly employed at the Laboratory during the war; **William H. Chambers,** who recently received his Ph.D. from Ohio State University; **Harold F. Plank,** former research assistant in M.I.T.'s Chemistry Department; and **Marshall N. Rosenbluth,** from the Department of Physics of Stanford University.

Henry B. Fry has been appointed Deputy Manager of AEC's New York Operations Office. Acting Deputy Manager since last February, he will be responsible for coordinating technical and administrative programs.

NECROLOGY

John T. Tate (May 27, 1950). As editor of the *Physical Review* since 1926 and adviser on publications of the American Institute of Physics, Dr. Tate devoted much of his life to expediting publication of results of scientific research. He was also research professor in physics at the University of Minnesota up to the time of his death, and contributed to the literature on electron impact phenomena in gases and electron interactions.

MEETINGS

British Association for the Advancement of Science (Annual Meeting)—Birmingham, England, Aug. 30–Sept. 6

American Chemical Society (118th National Meeting) and 6th National Chemical Exposition—Chicago, Ill., Sept. 3–8

Institute of Radio Engineers (West Coast Convention)—Long Beach, Calif., Sept. 13–15

International Congress of Electron Microscopy, sponsored by the French Society of Theoretical and Applied Microscopy—Paris, France, Sept. 14–22

National Congress of the Italian Physical Society—Bologna, Italy, Sept. 15–20

International Conference on Spectroscopy at Radiofrequencies—Amsterdam, Holland, Sept. 18–23

National Congress of Radiotherapy, Radiobiology, and Medical Physics—Bologna, Italy, Sept. 24–25

National Electronics Conference—Chicago, Ill., Sept. 25–27

Faraday Society, General Discussion on Spectroscopy and Molecular Structure, and Optical Methods of Investigating Cell Structure—Cambridge University, Cambridge, England, Sept. 25–28

National Academy of Sciences—General Electric Research Laboratory, Schenectady, N. Y., Oct. 9–11

Institute of Biology and Atomic Scientists Association, joint meeting to discuss "Biological Hazards of Atomic Energy"—Royal Institution, London, England, Oct. 20–21

Institute of Radio Engineers and American Institute of Electrical Engineers Conference on Electronics Instrumentation in Nucleonics and Medicine—New York, Oct. 23–25

1950 Metal Show, the American Society for Metals—Chicago, Ill., Oct. 23–27

American Chemical Society (119th National Meeting)—divided, Boston, Mass., Apr. 1–5, 1951; Cleveland, O., Apr. 8–12, 1951.

1st National Congress of Applied Mechanics—Illinois Institute of Technology, Chicago, Ill., June 11–16, 1951.

PRODUCTS and MATERIALS

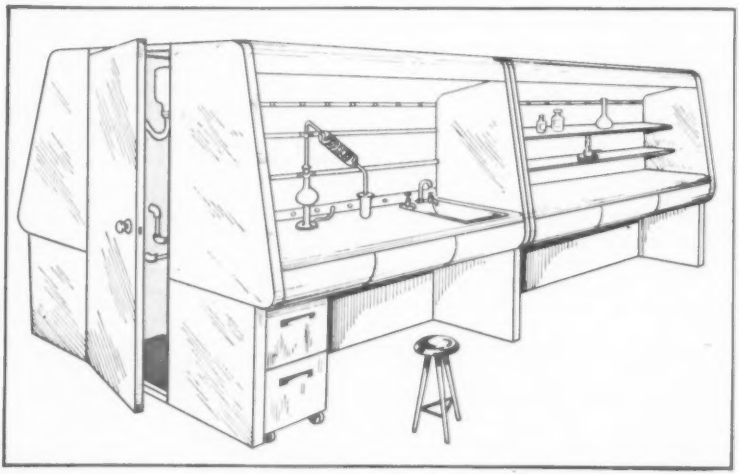
A DESIGN FOR LABORATORY FURNITURE

The laboratory furniture pictured here* illustrates how proper design would enable a manufacturer to use standardized subassemblies in customized equipment. Besides making the use of mass-production techniques possible and thus reducing the first cost of equipping a laboratory, this design would allow later changes by the user to meet demands of varying research.

These units were planned by Donald Dailey, Philadelphia, Pa., industrial designer, at the request of Allegheny Ludlum Steel Corporation's *Steel Horizons*. Mr. Dailey based his designs on two premises. First, space requirements for research do not vary substantially with the type of research. That is, a chemist and a biologist use the same types of space—for experimentation, for office work, for storage and filing. Second, major economies can be effected by mass production. Equipment must be standardized to make this possible.

Application of these ideas is evident in the design. End pieces and tops with built-in lights are standard on all benches. Back panels would be interchangeable. One panel would have rods for chemical apparatus clamps; another would have racks for mounting electrical equipment; another, shelves for biological materials and animal cages. The panels would have service outlets in a strip across the bottom where required. For use in low-level radioactivity work, the bench could be equipped with a sliding plastic shield on the front and a back panel with a

* This equipment is not in production and is thus not for sale.



filtered air inlet and an exhaust blower.

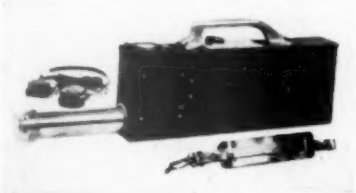
Stainless steel, stone or plastic bench tops, with or without sinks, would be provided.

The units could be placed against a wall, or, as shown in the illustration, back-to-back with a space for services between them.

Storage and filing units equipped with casters would roll under the benches. They could be moved as required; more storage space could be provided by adding more units.

While "custom" units are thus provided for specific types of research, the various subassemblies could be mass produced. The components could be formed of stainless steel by bending, die forming, drawing, and welding.

This equipment is not in production. These designs illustrate, however, what appears to be a growing trend towards modular, adaptable equipment.



FIELD SURVEY METER

Spinlab, 1003 Highland Ave., Knoxville, Tenn. The Prospectoscope 105-C is designed for the surveying of large areas for radioactive minerals. A Geiger tube of 2 in. diameter and 26 in. long is used. Operating at 1,050 volts, the tube has a $\frac{1}{16}$ in. brass cover to exclude beta particles. A rate meter with a scale marked from 0 to 10, headphones, and a loudspeaker are provided. Scale multipliers of 1, 2, 5, 10, and 20 extend the range. Background corresponds to a reading of 7 on the lowest range, and 10% changes in background level can be detected.

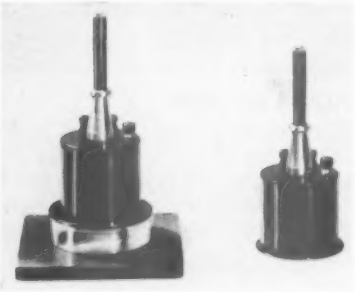
ALPHA COUNTER

Clarkstan Corp., 11921 W. Pico Blvd., Los Angeles 64, Calif. The model 501 alpha counter is designed for the detection of radioactive ore and elements. Scintillations caused by alpha particles on an activated phosphor screen are magnified by a lens system and viewed through an eyepiece. The device is claimed to detect all uranium ores.

RADIATION MONITOR

Kelley-Koett Mfg. Co., Covington, Ky. The model K-900 radiation monitor, equipped with an aluminum thin-wall Geiger tube, is sensitive to both beta and gamma radiation. A 115-volt a-c count-rate meter permits selection of 15 or 45 sec time constants, while a flashing neon light and variable volume speaker respond to increases in radioactive levels. Ranges of 1,000 and

10,000 cpm full-scale are provided. Geiger tube voltage is adjustable from 500 to 1,000 volts. Probe has wide slot on one side to allow differentiation between beta and gamma radiation.



ISOTOPE ANALYSIS UNIT

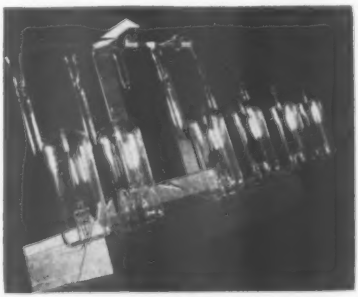
Landsverk Electrometer Co., Pippin Road, Cincinnati 31, Ohio. The Landsverk Analysis Unit consists of an ionization chamber with a quartz-fiber electrometer as the indicator. It is claimed to have a beta sensitivity of 0.001 μc with S^{35}, which can be read within 2 to 5% within 10 min. C^{14} shows an equal sensitivity, and 1 μc of I^{131} or P^{32} in 100 ml of liquid can be read to about the same accuracy. Small wet or dry samples can be placed on removable base, while larger wet samples to 150 ml are mounted in a special polystyrene dish. The unit is 3 in. in diameter.

ISOTOPE REVISIONS

Isotope Division, U. S. Atomic Energy Commission, Oak Ridge, Tenn., has announced reduced prices for S^{35} as H_2SO_4, S^{35} as BaS, Ca^{45} with an activity of 0.5 mc/gm, and Ca^{45} with an activity of 25 mc/gm. Also, the following new isotope forms are now available: S^{35} as sulfur, Ca^{45} with an activity of 1 c/gm, and Cr^{51} with an activity of 500 mc/gm. Revisions were announced in Supplement No. 4 to the AEC Isotopes Division Catalogue and Price List No. 3.

ALPHA-BETA-GAMMA COUNTER

Nuclear Instrument & Chemical Corp., 229 West Erie St., Chicago 10, Ill. The model 2611 portable alpha-beta-gamma counter is designed to check all types of electromagnetic radiation. The unit is battery operated and uses a thin mica end-window probe with a window density of 1.4 mg/cm^2. The meter reads in cpm for alphas and betas, in mr/hr for gammas. Selector switch permits choice of 0.2, 2, or 20 mr/hr full scale. Headphones can be used.



ION PRESSURE GAGE

Westinghouse Electric Corp., 306 4th Ave., Pittsburgh 30, Pa. A new ion gage for measuring extremely high vacuums is designed to detect pressures as low as 1×10^{-12} in. Hg. Greater

(Continued on page 98)

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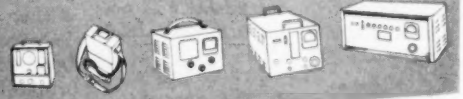

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sensitivity is said to have been achieved by eliminating false readings due to X-rays produced in the ionization process.

G-M COUNTER TUBE

Eclipse-Pioneer Division, Bendix Aviation Corp., Teterboro, N. J. The type BS-1 low sensitivity, self-quenching G-M counter tube has a background of approximately 100 cps and an operating voltage of 700 volts d-c. It has a minimum plateau length of 80 volts. Plateau slope is not in excess of 0.2% per volt.

AIR FLOW METER

Hastings Instruments Co., Inc., Hampton, Va. The Air Ventimeter measures ventilation air flow with a miniature nondirectional probe. The probe is ⅜ in. long and ¼ in. in diameter. Operating on the noble metal thermopile principle, the device measures velocities from 5 ft/min to 6,000 ft/min. A temperature compensating feature is incorporated, and indicators are available for operation on 115-volt a-c or battery power supplies.

PORTABLE LEAD SHIELD

Atomic Instrument Co., 160 Charles St., Boston, Mass. The model 805 lead shield is designed for carrying isotopes in standard 30-cc vaccine or glass-stoppered bottles. The shield has aluminum inner and outer shells and a minimum lead wall thickness of 1 in. The inner chamber measures 1½ in. × 4 in. Positioning of the locking lugs is said to prevent contamination by not allowing the cover face to lie against flat surfaces.

INSULATING TAPE

Bishop Mfg. Corp., 254 West 31st St., New York 1, New York. Biseal self-bonding insulating tape is a polyethylene derivative which fuses quickly to a solid moisture- and waterproof mass. Besides its use as an electrical insulator, the tape can be used to seal glass or plastic tube joints. The material from which the tape is made can be obtained in bulk for use as a chemical container lining. This material resists corrosion by inorganic acids, bases, and oxidants, but is affected by organic solvents. It is said to be unaffected by temperature changes and contact with metals.

FILM-PROCESSING COOLER

Bar-Ray Products, Inc., 209 25th St., Brooklyn, N. Y. Designed for processing X-ray film, this refrigerated water-cooling unit is 12 in. high and 17 in. square. The unit has a capacity of 15 to 60 gallons of water per hour, entering at 85° F and leaving at 68° F. Manufacturer claims instant cooling and automatic water delivery at 68° F, with no buildup time required. Other units are available with capacities to 180 gallons per hour.

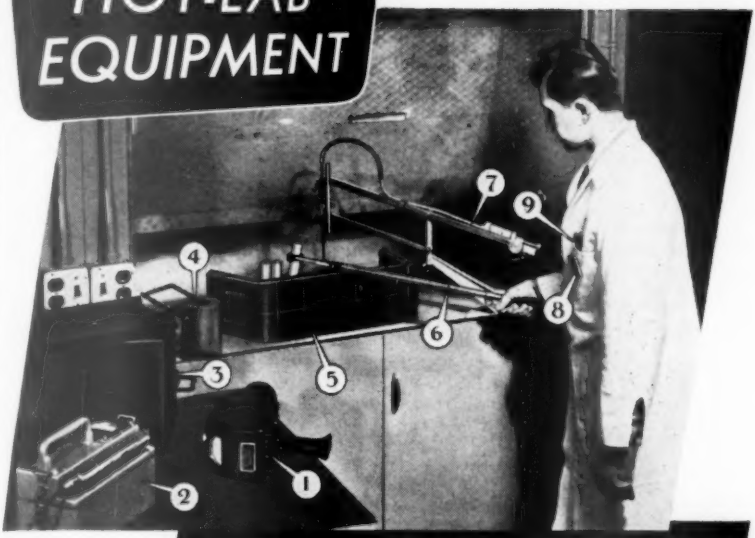
LITERATURE AVAILABLE

Recording Counters. Illustrated bulletin lists latest recording mechanical counters actuated by electrical impulses. *Streeter-Amet Co., 4101 Ravenswood Ave., Chicago 13, Ill.*

D-C Power Supplies. Folder describes the specifications and applications of Varicell d-c power supplies. *The Superior Electric Company, Hannon Ave., Bristol, Conn.*

Nickel Alloys. Two new technical bulletins describe the properties of high nickel alloys. Bulletin T-7 deals with Inconel and Inconel X, while Bulletin T-9 discusses "K" Monel and "KR" Monel. *International Nickel Co., 67 Wall St., New York 5, N. Y.*

HOT-LAB EQUIPMENT



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(6) E-17 Remote Handling Tongs
(7) E-18A Remote Pipetting Device
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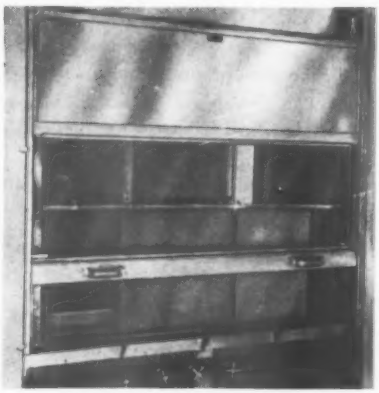

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olism and physiology of sheep and the influence of nutrition on wool production. The work is being undertaken by the organization's Division of Biochemistry and General Nutrition and the University of Adelaide.

Methods of assaying C^{14} in tissue and fluids have been developed. Investigations into the absorption and utilization of cobalt in sheep are being conducted with Co^{60}.

PATENTS RELEASED

The Atomic Energy Commission has released 16 more patents for nonexclusive, royalty-free use. Copies of the patents listed here can be obtained from the U. S. Patent Office, Washington, D. C. For licenses, apply to the Chief, Patent Branch, Office of the General Counsel, U. S. Atomic Energy Commission, Washington, D. C.

Neutron Meter (2,506,944), L. H. Stauffer, T. M. Snyder. Neutron-sensitive chamber surrounded by moderator measures radiation intensity.

Treatment of Pitchblende Ores (2,506,945), H. C. Thomas, A. S. Tomcufcik. Process for recovering Ra and U.

Apparatus for Controlling Magnetic Fields (2,507,301), H. W. Fulbright. Used with mass spectrograph to keep field constant over a long period of time.

Leak Testing Device (2,507,321), D. W. Sherwood. For testing evacuated apparatus.

Distillation Apparatus (2,508,234), D. Duffey. For purifying alkaline earth metals.

Apparatus for Purifying Gases (2,508,989), M. M. Brandegee. Used for corrosive gases.

Insulating Column Structure (2,509,009), J. L. McKibben. For separating bodies at widely different potentials.

Vacuum Tube Flux Meters (2,509,394), R. Kinslow. Indicates magnetic field intensity and uniformity as function of plate voltage.

Mechanical Couplings (2,509,669), L. B. Borst. For detachably securing together abutting graphite blocks.

Radioactivity Measuring Devices (2,509,700), J. A. Simpson, Jr. Measures contamination of hands or other portions of the body; uses two parallel alpha-sensitive counters.

Methods of Producing Uranium Fluorides and a Compound Produced Thereby (2,510,850), P. A. Agron, S. W. Weller. Uranium heptadecafluoride is produced.

Catalysts for Fluorination (2,510,864), G. H. Cady.

Methods for Regenerating Antimony Pentafluoride from Spent Antimony Halides Resulting from the Fluorination of Organic Chlorides (2,510,872), F. B. Downing.

Systems for Measuring Limited Current Changes (2,510,930), K. G. MacLeish.

Chemical Method for Concentrating Isotopes of Carbon (2,511,667), M. Calvin, P. E. Yankwich. Repeated decarboxylation and synthesis of certain phthalates or malonates is used.

Electric Discharge Device (2,512,538), W. R. Baker. Gaseous discharge device of large power rating is capable of passing thousands of amperes of pulsed current and has precisely controlled ignition time.

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